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Japanese Technology Evaluation Center
World Technology Evaluation Center

JTEC
WTEC

JTEC/WTEC Program Summary

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Coordinated by

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JAPANESE TECHNOLOGY EVALUATION CENTER
WORLD TECHNOLOGY EVALUATION CENTER

SPONSOR The World Technology Evaluation Center (WTEC) is a companion to the long-established Japanese Technology Evaluation Center (JTEC) at Loyola College. JTEC/WTEC is operated for the Federal Government to provide assessments of foreign research and development (R&D) in selected technologies. The National Science Foundation (NSF) is the lead support agency. Paul Herer, Senior Advisor for Planning and Technology Evaluation, is NSF Program Director for the project. Other sponsors of WTEC and JTEC include the National Aeronautics and Space Administration (NASA), the Department of Commerce (DOC), the Department of Energy (DOE), the Office of Naval Research (ONR), the Defense Advanced Research Projects Agency (DARPA), the U.S. Army, and the U.S. Air Force.

PURPOSE The steady integration of the world market system and the pressures of competition in high technology have stimulated the consolidation of global R&D among companies and nations. The resulting trends are for faster paced development of technologies directly competitive with those in the U.S. As Asian and European nations and corporations become leaders in research in targeted technologies, it is essential that the United States have access to the results. JTEC/WTEC provides the important first step in the process by alerting U.S. researchers to accomplishments in other nations. JTEC/WTEC findings are also useful in formulating government research and trade policies.

APPROACH The assessments are performed by panels of about six U.S. technical experts. Panel members are leading authorities in the field, technically active, and knowledgeable about both U.S. and foreign research programs. Each panelist spends about one month of effort reviewing literature, making assessments, and writing reports on a part-time basis over a twelve-month period. Panels conduct extensive tours of university and industrial research facilities in selected foreign host countries. To provide a balanced perspective, panelists are selected from industry, academia, and government.

ASSESSMENTS The focus of the assessments is on the status and long-term direction of foreign R&D efforts relative to those of the United States. Other important aspects include the evolution of the technology and the identification of key researchers, R&D organizations, and funding sources.

REPORTS The panel findings are presented to workshops where invited participants critique the preliminary results. Final reports are distributed by the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161 (703-487-4650). The panelists also present technical findings in papers and books. All results are unclassified and public.

LOYOLA COLLEGE The function of the JTEC/WTEC staff at Loyola College is to coordinate assessments and to produce reports of the highest professional quality. JTEC/WTEC helps select topics, recruits experts as panelists, organizes tours of foreign laboratories and industrial sites, assists in the preparation of workshop presentations, and provides editorial assistance for the final report.

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Note: This document contains JTEC and WTEC final report summaries that have been edited by the JTEC/WTEC and NSF staffs based on the original reports prepared by the JTEC and WTEC panels. While the editors have made every effort to remain faithful to the intent of the original authors, final editorial responsibility lies with the JTEC/WTEC staff.

FOREWORD

This report is a summary of a series of reports prepared through the Japanese technology evaluation program and the world technology evaluation program, both sponsored by the National Science Foundation (NSF). Originally coordinated by Science Applications International Corporation (SAIC), the Japanese Technology Evaluation Center is currently administered by Loyola College in Maryland as JTEC. The purpose of the JTEC program is to assess research and development efforts ongoing in Japan in specific areas of technology, to compare these efforts and their results to U.S. research in the same areas, and to draw conclusions regarding their impact on the economic competitiveness of the United States over the next ten to fifteen years.

The companion World Technology Evaluation Center (WTEC) program, also administered for NSF by Loyola College, employs the time-tested methodology developed by JTEC to examine the technology of countries other than Japan. WTEC has completed its first study and is expected to complete its second in the coming year.

Over the past decade, the United States' competitive position in world economic markets appears to have eroded substantially. Market share formerly held by U.S. companies in areas such as consumer products, microelectronics, and telecommunications has been lost to Japan and, to a lesser extent, European nations. As U.S. technological leadership is challenged in areas of previous dominance, such as aeronautics, space, and nuclear power, many governmental and private organizations seek to set policies that will help maintain U.S. strengths. To do this effectively requires an understanding of the relative position of the United States and its competitors.

Many U.S. organizations support substantial data gathering and analysis efforts directed at nations such as Japan. But often the results of these studies are not widely available. At the same time, government and privately sponsored studies that are in the public domain tend to be "input" studies. That is, they provide enumeration of inputs to the research and development process, such as monetary expenditures, personnel data, and facilities, but do not provide an assessment of the quality or quantity of the outputs obtained. Studies of the outputs of the research and development process are more difficult to perform because they require a subjective analysis performed by individuals who are experts in the relevant technical fields. It takes experts in the technologies even to assemble expert panels to perform such assessments.

The National Science Foundation staff includes professionals with expertise in a wide range of technologies. These individuals provide the technical expertise needed to assemble panels of experts that can perform competent, unbiased, technical reviews of research and development activities. Furthermore, a principal activity of the Foundation is the review and selection for funding of technical proposals. Thus the Foundation has both experience and credibility in this process. The JTEC/WTEC activity builds on this capability.

Specific technologies, such as telecommunications, biotechnology, and nuclear power, are selected for study by individuals in government agencies who are interested in obtaining the results of an assessment and who are able to contribute to its funding. A typical assessment is sponsored by two to four agencies. In cooperation with the sponsoring agencies, the Foundation selects a panel of experts to conduct the assessment. Administrative oversight of the panel is provided by Loyola College in Maryland, which operates JTEC and WTEC under an NSF grant.

Panelists are selected for their expertise in specific areas of technology and their broad knowledge of research and development both in the United States abroad. Of great importance is the panelists' ability to produce an assessment that is comprehensive, informed, and unbiased. Most panelists have travelled frequently to Japan and/or Europe. Nevertheless, as part of the assessment, the panel as a whole travels to Japan (or other relevant countries) to spend one full week visiting research and development sites and meeting with researchers. These trips have proven highly informative; the panelists have been given broad access to both researchers and facilities. After the trip, the panel conducts a one-day workshop in the U.S. to present its findings. The panel then completes a written report that is intended for widespread distribution.

Assessment results are distributed to the widest feasible audience. Representatives of the foreign hosts and members of the media are invited to attend the workshops. The final reports are distributed to a general mailing list and to others upon request. Beyond the initial mailing, all completed reports are made available through the National Technical Information Service (NTIS). Furthermore, publication of results is encouraged in the professional society journals and magazines; articles have appeared in *Science, the IEEE Spectrum, Chemical and Engineering News*, and others. The results of the first six assessments were compiled in *Gaining Ground*, a book coauthored by George Gamota and Wendy Frieman. Recently JTEC and WTEC have begun testing videotapes and other media as means of distributing panelists' findings.

Over the years, the reports have found their way into the policymaking process of many agencies and organizations. Many of the reports are used by foreign governments and corporations. Indeed, the Japanese have used the reports to their advantage, as the studies provide an independent assessment attesting to the quality of Japan's research.

Although Japan has been the primary focus of this assessment activity, many other countries have traditions of excellence in science and technology. The methodology developed and applied to the study of research and development in Japan is equally relevant to other countries, such as the leading industrial nations of Europe. In general, the United States can benefit from a better understanding of cutting-edge research that is being conducted outside its borders. Improved awareness of international developments can significantly enhance the scope and effectiveness of international collaboration and thus benefit all of our international partners in collaborative research and development efforts.

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INTRODUCTION

By the end of 1992, the JTEC program will have been in existence for over nine years and will be nearing the completion of its twenty-sixth study. In addition, the companion World Technology Evaluation Center program has completed one study and will have nearly completed its second by the end of 1992. Some technologies -- for example, those in the area of computer science -- have been studied several times because of the great interest in the subject and the rapid changes in the technology. This continuity, combined with the institutional memory of several people who have been involved with the JTEC program since its inception, make it possible to assemble a picture of the evolution of Japanese technology and to compare it with technological development in the United States. Because of the time that has elapsed since the earlier reports, it is also possible to see which of the predictions came true, which did not, what was missed, and, finally, why some predicted events did not come to pass. The ICOT Fifth Generation project is an example. Many people consider that project a disappointment; my own opinion is that, although it did not achieve all of its goals, it taught the Japanese many things that are critical to the next phase of advanced computing. The 1987 study, *Advanced Computing in Japan*, dealt almost exclusively with the Fifth Generation program, and the 1990 study reflected on the degree to which that project succeeded. The upcoming JTEC report on knowledge-based systems in Japan will include a section on ICOT. One preliminary finding from that report is that ICOT has made some impressive achievements, particularly in the development of the "KL1" family of parallel symbolic programming languages. The ICOT program has now been extended for another three years.

Each JTEC or WTEC study provides a current view of a particular Japanese or European technology. It also provides a snapshot of a particular technology and its relationship to a possible range of products. To capture the spirit of this undertaking, the National Science Foundation has asked us to combine the executive summaries of all the reports in a single document and to identify some issues that cut across several of the studies. This program summary presents twenty-five executive summaries. The seven earliest studies, those completed between 1984 and 1988, are summarized very briefly (fuller summaries of these studies have been published in the book *Gaining Ground*, by George Gamota and Wendy Frieman). Eleven additional studies were summarized in some detail in the *JTEC Program Summary* published in September of 1991; these summaries have been somewhat abridged in this edition. The seven most recent studies, completed between the fall of 1991 and the fall of 1992, are summarized more fully.

The reports have been arranged according to generic technological areas, so readers can make correlations between similar areas and compare changes reported by similar studies conducted at different times. I have chosen the National Critical Technologies List (1991), prepared by the President's Office of Science and Technology Policy, as a template for grouping the JTEC studies. That list is a good example of existing technology lists that have appeared recently in Washington and worldwide. Others are, for example, the Department of Defense (DOD) Critical Technologies Plan (1991) and a list prepared by the Department of Commerce in 1990. There are several analogous Japanese lists, most notably a 1988 Ministry of International Trade and Industry (MITI) document that ranks the United States and Japan in a wide range of industrial technologies. Similar strategic thinking is evident in the 1990 list of research projects supported by the Commission of the European Communities (EC). These lists have many common themes and, not too surprisingly, include most of the topics that were studied by the JTEC teams. Following this introduction is Table 1, which compares the JTEC studies with both the National and the DOD critical technologies lists.

As a glance at the titles of all the JTEC studies makes clear, JTEC's sponsoring agencies have emphasized technologies related to information services, although much work has been done in the areas of materials, manufacturing, and space technology. No studies have directly addressed pharmaceutical, medical, and environmental technologies, though the Bioprocess Engineering study (completed in 1992) and the Separation Technologies study (completion expected in early 1993) do cover some relevant material.

One JTEC study, *JTEC Panel Report on the Japanese Exploratory Research for Advanced Technology (ERATO) Program*, was unlike all the others in that it looked at a Japanese attempt to initiate a major new program in basic research. Although the ERATO program had been in existence for some years, the Japanese had not reviewed it until the JTEC team visited Japan. It is hard to judge the successes and failures of this novel program, because its main objective is to develop a cadre of people in certain areas, do good work, and then disperse the scientists and engineers throughout the Japanese technical community. The ERATO work falls into two main categories: physical and biological. Nearly half the projects have been in biotechnology, a fact that indicates the importance the Japanese attach to this area for the future.

Japanese Strengths and Weaknesses

It is very difficult to make categorical statements about a nation's strengths and weaknesses in a technology without using many caveats. Unfortunately, too many caveats make the argument less persuasive. However, without the caveats, statements can be taken out of context and wrong perceptions created.

Nevertheless, it is necessary to synthesize and present data so that policymakers and the nontechnical community can easily understand the importance and the implications of the findings. Table 2, which follows the introduction, relies on an overview of the studies to summarize the Japanese position. This table makes it obvious that the single most important Japanese strength is products, not only in the area of electronic components, but also in many other areas. Another interesting factor is that in many cases Japanese R&D is competitive with that in the U.S. Japanese technology is weak in many basic research areas; but by launching the ERATO program, the Japanese show that they are trying to offset this deficiency.

The European Challenge

In recent years there has been an increasing awareness among the sponsors of the JTEC program that the technological challenge facing the United States comes not only from Japan, but from Europe and potentially from many other parts of the world. This inspired the formation of the World Technology Evaluation Center. WTEC completed its initial assessment, *European Nuclear Instrumentation and Controls Technology*, in late 1991. Combined with the instrumentation and controls section of the JTEC *Nuclear Power* report, this study provides a fairly complete view of how the United States compares to the rest of the world in this vital energy technology.

WTEC's second international assessment will examine satellite telecommunications technology in both Europe and Japan. NSF and the other agencies supporting this initiative hope that this will be the first in a series of global technology assessments. WTEC has now initiated an assessment of submersible vehicle technologies in the former Soviet Union and Western Europe. Topics under consideration for future WTEC studies include European display technologies and construction.

Although it is too early to draw general conclusions from the WTEC program, there is no doubt that the United States must increase its awareness of significant technological developments outside its borders, wherever in the world they may be found. The WTEC program is aimed at this need.

Lessons Learned

Perspective is one of several benefits that accrue from compiling the JTEC/WTEC studies. The studies suggest that if the present trends continue, the Japanese will increasingly dominate high-technology markets. This is not to say that they will dominate all high technology. But if there is a large market, they will be in it and will be trying to perform the state-of-the-art work that will ensure that their products will be the best. High quality and state-of-the-art work are Japanese hallmarks. The U.S. can react to these challenges, and in fact has turned a corner in an area that was given up by many as a lost cause - semiconductor manufacturing. Recent advances by U.S. industry giants such as Intel and SEMATECH (a cooperative industry research institute) have made the U.S. competitive again.

Japan's economic strategy is tied to end-use products that involve long-term investments in R&D. Not all Japanese investments pay off, but enough do to make that industrial policy a very attractive one. The Japanese do not dabble in research in the hope that something will evolve out that has a commercial payoff. Their research is tied to specific problems that are related to products; those products are leveraged in markets that the Japanese control or intend to control.

Luckily for the United States, not all Japanese investments have been successful in pulling the country ahead. One example that JTEC teams have tracked for seven years is software. Although the Japanese have made large investments in this area, even creating "software factories," they have not penetrated the world market. To be sure, they have not given up; recently they acknowledged the difficulty in the next step of advanced computing and called for an international effort to combine forces and initiate the sixth generation of computing.

Another area where Japanese industrial policy is encountering difficulties is in the development of the nuclear breeder reactor, *Monju*. The U.S. abandoned this technology fifteen years ago because of potential economic, health, safety, and political problems. In spite of this, Japan continued to pump most of its advanced reactor R&D investments into this one area. Today, as the first shipment of plutonium fuel is on its way to Japan, we are witnessing a worldwide reaction that can only be described as embarrassing to Japan. In sum, this is not to say that industrial policy is bad or good, but only that it must be balanced against many considerations; decisions should be reviewed periodically to assure that the original underpinnings and assumptions are still valid.

Although basic research in many technologies is one of Japan's weaknesses, it is improving steadily. In some areas -- for example, superconductivity and electronic materials -- Japan is on a par with the United States.

As the Japanese have improved their basic research, they have also strengthened their university research and coupled it with industry. University research has traditionally played a secondary role in Japan's research enterprise. Early JTEC teams were so disappointed with what they observed that for a long while few teams even wanted to visit universities except to pay social calls. Today that is changing. Recent JTEC teams have noted that not only has university research improved steadily but, even more significantly, Japanese industry is paying more attention to what is going on at universities. The Japanese government has recognized the barriers between university and industrial research and has begun to remove them and to encourage cooperative research.

By most accounts, basic research in Japan is focused in certain areas. Because of this focus, some would call it applied rather than basic research. Many of these arguments are academic, because the quality and character of work completely determine its value. Nevertheless, it is important to note that really unfettered research seldom takes place in Japan. Much of the basic research (except for the ERATO projects) ultimately is tied to some need and has a well-thought-out road map to possible applications. Japan and the United States tend to have different approaches to managing basic research efforts. U.S. research often concentrates on solving ever more difficult problems, whereas the Japanese focus on solving incremental problems closely tied to product development. The United States tries for the giant leaps; Japan consistently strides ahead.

In some critical areas -- for example, artificial intelligence and software -- the Japanese have decided to fund basic research in the U.S. Some of the work is being done at prestigious U.S. universities, and some at Japanese-owned R&D centers at various U.S. locations: Princeton, Palo Alto, and Michigan. The work there is first class, and most of the results are published in U.S. journals. To be sure, the Japanese scrutinize the results for possible applications to their product lines.

The Japanese apparently have chosen superconductivity as the flagship of their basic research efforts, and have been competing successfully worldwide. Their focus is on high-temperature superconductor materials.

Lastly, when JTEC was started, one of the fears was that it would be extremely difficult to get useful information from the Japanese because they were perceived as secretive, and because the language barrier would give them an easy way not to tell U.S. visitors about the important things that were going on. JTEC panels found the opposite to be true. Like most researchers, the Japanese are eager to share their work. In most cases, they have provided far more information than we would have expected to glean from comparable visits to U.S. companies. To be sure, good advance work has been necessary to ensure that we visited the right places and asked the right questions; but very seldom has a JTEC team been denied access even to assembly plants that it wished to visit. The hardest visits to arrange were those to U.S. subsidiaries in Japan, which operated more like companies in the U.S. Although language has not really presented a problem, whenever a JTEC team included at least one Japanese-speaking member, more information was exchanged.

The Japanese view JTEC very positively. They believe in the importance of gathering information, and they are very good at it. Their balance of trade with the U.S. in information gathering is roughly 3:1; that is, Japan buys three times more information from the U.S. than the U.S. buys from Japan. In terms of people exchanged, the numbers are even more skewed. For every ten Japanese scientists or engineers who visit the U.S. for an extended time, only one American goes to

Japan. The imbalance is so great that the Japanese government even funds Americans to travel to Japan and spend time in Japanese laboratories.

In the West, and particularly in the U.S., being associated with a technological failure is usually detrimental to one's career. In Japan, decisions are made by consensus, and risks are shared by all concerned. If a program fails to meet its technological objective, the people associated with the undertaking share the disappointment; but seldom does such a failure threaten an individual's career, because the group made the decisions. Moreover, the Japanese try to learn from failures, documenting findings just as if the results had been positive. As a result, there appears to be much less "going over the same ground" in Japan than in the U.S.

In 1992 the world is experiencing a recession, and Japan and Europe are not immune from its effects. Industrial funding for R&D in the U.S. is down, and there is talk that Europe is following suit. No such signs are evident in Japan; if they follow their previous strategy, they will use this time to increase R&D rather than cut it back. If there is one soft spot in Japan, it is industrial support of university research: although it has been going up in recent years, there is talk that it is levelling off. Time will tell, and we hope our current and future JTEC reports will provide us with more detailed information.

Conclusion

JTEC/WTEC has initiated thirty studies of foreign technology over the past nine years (five are still in progress, and final reports are expected in 1993). This series of studies gives a fairly comprehensive picture of the status and trends, and the strengths and the weaknesses, of Japanese R&D over a wide spectrum of strategic technology areas. This document summarizes the results of the first twenty-five studies. It is inevitable that this summation will be vulnerable to misinterpretation when taken out of the context of the full reports. Nevertheless, even a brief perusal of these summaries conveys an overall impression of Japanese R&D that is scarcely subject to misinterpretation: Japan is engaged in a systematic effort to achieve parity with, or superiority over, the United States in virtually every technology that is of current or potential economic significance. The Europeans are evidently following a similar path of strategic investment in high technology. The mechanisms by which Japan and Europe have pursued this strategy, and the extent to which they are succeeding, cannot help but be of great interest to policymakers in the United States and in the rest of the world. The Japanese make no secret of their objectives or methods in pursuing this strategy; quite the contrary, they offer the rest of the world a possible blueprint for the pursuit of economic prosperity through thoughtful long-range investment in science and technology. The authors of the JTEC and WTEC reports and the other contributors to this summary report hope that readers will find this information to be a useful contribution to the debate over how valid and applicable this Japanese model of technological and economic development is to the rest of the world.

Too many people have contributed to the overall JTEC/WTEC effort to list here, though we are grateful for all of their work -- and particularly for the work of the panelists and chairpersons of all the study teams, without whom there would have been no JTEC program. I would also like to thank the numerous Japanese and European hosts, who have been very gracious in accepting our teams, sharing information, and making our visits very memorable. I will conclude by thanking those whose efforts have most directly led to the success of JTEC/WTEC and to the publication of this document: Paul Herer of the National Science Foundation, who manages the JTEC/WTEC program for NSF; Frank Huband, formerly in charge of JTEC at NSF and now executive director of the American Society for Engineering Education; Duane Shelton, principal investigator for the JTEC/WTEC grants at Loyola College; and, last but not least, Geoff Holdridge of JTEC, who edited and produced this summary report.

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Table 1
JTEC Studies Compared With National and Department of Defense Critical Technologies

National Critical Technologies	JTEC Studies	DOD Critical Technologies
MATERIALS		
Synthesis and processing	Advanced Materials (1986) Superconductivity (1989) Separation Technologies (1992)*	Superconductors
Electronic and photonic materials	Opto- and Micro-Electronics (1985) Superconductors (1989) *ERATO* (1988)	Semiconductor materials and integrated circuits
Ceramics	Advanced Materials (1986)	
Composites	Advanced Composites (1991) Polymer Composite Manuf. (1992)*	Composite materials
High-performance metals and alloys		
MANUFACTURING		
Flexible computer integrated manufacturing	Computer-Integrated Manufacturing and Computer-Assisted Design [CIM and CAD] for the Semiconductor Industry (1988) *Space Robotics* (1991)	Machine intelligence and robotics
Intelligent processing equipment	Mechatronics (1985) Knowledge-Based Systems (1992)* *Polymer Composite Manuf.* (1992)*	
Micro- and nanofabrication	MicroElectroMechanical Systems [MEMS] (1992)**	
System management technologies	*Nuclear Power* (1990) *Construction* (1991) Material Handling (1992)	
INFORMATION AND COMMUNICATIONS		
Software	Computer Science (1984) Advanced Computing (1987, 1990) *Machine Translation* (1991) *Database Systems* (1991) Knowledge-Based Systems (1992)*	Software producibility

Table 1
JTEC Studies Compared With National and Department of Defense Critical Technologies

National Critical Technologies	JTEC Studies	DOD Critical Technologies
Micro- and opto-electronics	Opto- and Micro-electronics (1985) *Telecommunications* (1986) *Satellite Communications* (1992)* *ERATO* (1988) X-Ray Lithography (1991) *Separation Technologies* (1992)*	Photonics
High-Performance Computing and Networking	Advanced Computing (1987, 1990) *Knowledge-Based Systems* (1992)*	Parallel computer architecture
High definition imaging and displays	High Definition Systems (1991) Displays (1992) European Displays (1992)**	
Sensors and signal processing	Advanced Sensors (1989) MEMS (1992)** *Satellite Communications* (1992)*	Data fusion Passive sensors Signal processing Sensitive radars
Data storage and peripherals	Advanced Computing (1987, 1990) *Database Systems* (1991)	
Computer simulation and modeling	CIM and CAD (1988) *Advanced Computing* (1990) *Space Propulsion* (1990) Knowledge-Based Systems (1992)*	Simulation and modeling Computational fluid dynamics
BIOTECHNOLOGY AND LIFE SCIENCES		
Applied molecular biology	Biotechnology (1985) *ERATO* (1988) Bioprocess Engineering (1991) Separation Technologies (1992)*	Biotechnology materials and processes
Medical technology	*Separation Technologies* (1992)*	
AERONAUTICS AND SURFACE TRANSPORTATION		
Aeronautics	Polymer Composite Manuf. (1992)* Advanced Composites (1991) Space Propulsion (1990) *Displays* (1992)	
Surface transport technologies	Material Handling (1992) Superconductivity (1989) Polymer Composite Manuf. (1992)*	

Table 1
JTEC Studies Compared With National and Department of Defense Critical Technologies

National Critical Technologies	JTEC Studies	DOD Critical Technologies
ENERGY AND ENVIRONMENT		
Energy technologies	Nuclear Power (1990) European Nuclear Instrumentation and Controls (1991) *Separation Technologies* (1992)* *Polymer Composite Manuf.* (1992)*	
Pollution minimization, remediation, and waste management	Separation Technologies (1992)*	
NO NATIONAL OR DOD CRITICAL TECHNOLOGIES COUNTERPARTS		
	Telecommunications (1986) Space Robotics (1991) Machine Translation (1991) Submersible Vehicles (1992)*	

Note. * denotes study in progress; ** denotes study planned; *italic* type designates partial overlap.

Table 2
Japanese Strengths and Weaknesses

TECHNOLOGY	JAPANESE POSITION		
	Strong	Competitive	Weak
MATERIALS			
Carbon-fiber	Products	R&D	Basic Research
Carbon-carbon composites			R&D, manufacturing
High-strength polymers		R&D, products	Basic research
Electronic (Si & GaAs)	Products	R&D	II-VI materials
Biopolymers			All processes (but gaining)
Superconductors	Processing	R&D	Theory
ELECTRONICS AND INFORMATION TECHNOLOGIES			
Microelectronics	Memory chips	Logic chips	Microprocessors
Lithography	Optical & X-ray		
Displays	Products		
Machine translation	Products	R&D	European languages
Databases		Image & multimedia	Products
Memory storage	Optical	Magnetic	
Computers	Laptop components	Supercomputers, hardware	Workstations, PCs
Software	Factories	Software engineering	R&D, products
Sensors	Charge-couple devices	Products	Research
Telecommunications	Component & fiber optics	Mobile	Networks

TECHNOLOGY	JAPANESE POSITION		
	Strong	Competitive	Weak
ENERGY AND PROPULSION			
Nuclear power	Instrumentation & controls	Construction R&D	Computer code
Rocket propulsion		Liquid rocket	Scramjet technology, turbopumps
MANUFACTURING			
Flexible manufacturing systems	Products		
Software			Human-machine interface (but gaining)
Manipulators	Products	R&D	
Precision engineering	Products	R&D	
Robotics	Products	Systems	
Computer-integrated manufacturing	R&D, products		
Computer-assisted design		Applications	New concepts & tools

KEY

Some of the JTEC panels chose to present their basic conclusions in tabular form. Table 3 explains the notations used in the tables throughout this document. Figures use a variety of notations, which are explained under each figure.

Table 3
Explanation of the Notation:
Japan's Position Relative to that of the United States

Absolute Position		Rate of Change	
++	Far ahead	>>	Pulling away sharply
+	Ahead	>	Pulling away
0	Even	=	Holding position
-	Behind	<	Falling behind
--	Far behind	<<	Slipping quickly

I. Exploratory Research for Advanced Technology (ERATO) Program

THE JAPANESE EXPLORATORY RESEARCH FOR ADVANCED TECHNOLOGY (ERATO) PROGRAM

December 1988

William Brinkman, AT&T Bell Laboratories (Panel Cochair)

Dale Oxender, University of Michigan, (Panel Cochair)

Rita Colwell, University of Maryland

Joseph Demuth, IBM Thomas J. Watson Research Center

John Rowell, Bell Communications Research

Richard Skalak, University of California

Edward Wolf, Cornell University

SUMMARY

The Exploratory Research for Advanced Technology (ERATO) Program was initiated in 1981 by the Science and Technology Agency of the Government of Japan. Administered by the Research and Development Corporation of Japan (JRDC), the ERATO Program was formed "to foster the creation of advanced technologies and advancing future interdisciplinary scientific activities while searching for a better system of basic research," according to a JRDC brochure. The experimental program funds projects at $2 million to $3 million per year each for five years. It selects outstanding scientists as project leaders, who attract young scientists from Japan and abroad. The JTEC panel was able to review ten ERATO projects.

ERATO is designed to bring industry and university scientists closer, and to select subjects that will have a long-term impact on technology. Considerable freedom is allowed in how the money is spent. Sixty percent of the project members have been attracted from industry by the freedom to do basic research.

Project Descriptions

Ultra-Fine Particles Project (1981-1986). The project goal was to clarify the properties of ultra-fine particles and evaluate them for use in industrial materials. Ultra-fine particles are less than a micron in diameter, but are large compared to clusters of inorganic materials. The Basic Properties Group studied the use of electron microscopy to characterize fine particles, including the structures of Al_2O_3 fine particles and morphological changes in gold particles. The Physical Applications Group studied applications of ultra-fine particles, including possible electron and optical devices. Perhaps the most interesting results were on possible magnetic recording media using fine Fe particles embedded in an organic polymer. The Biological/Chemical Applications Group investigated use of fine polymer encapsulated Fe ultra-fine particles for magnetically controlled transport, and use of fine particles to measure and characterize flow in biological systems. The Formation Process Group focused on formation of unique ultra-fine particles such as chained particles and deposition of particles using high-velocity gas jets.

Amorphous and Intercalation Compounds Project (1981-1986). The project purposes were to synthesize materials with unusual structure, composition, and morphology, and to explore synthesis techniques. Emphasis was placed on amorphous materials, vapor growth processes, and magnetic properties for recording and other industrial applications. The Basic Properties Group served as a central materials characterization facility. It researched magnetic properties of elongated particles of amorphous materials grown by vapor deposition onto a textured substrate. The Intercalation Compounds Group investigated the intercalation of photoactive chemicals into inorganic layered materials. An optical memory was demonstrated. The work of the Amorphous Thin Films Group covered the magnetic, electric, and optical properties of amorphous and compositionally modulated thin films, as well as perpendicular magnet recording. The Amorphous Compounds Group carried out an extensive study of V_2O_5-based amorphous binary oxides using melt-quenched samples. The emphasis of the Special Ceramics Group was on production of nitride- and boride-based ceramics by chemical vapor deposition (CVD), and the exploration of plasma and laser enhancement of CVD for the synthesis of new ceramics.

Fine Polymer Project (1981-1986). This project emphasized polymer synthesis, producing new polymers and inventing new processes. The Molecular Design Group produced fine particles of single molecules of polystyrene and thin films of aromatic compounds, and found a low-temperature process for producing polyesters. The Selective Functional Design Group produced a very significant result. Using known methodology, Mr. Kiniwa prepared oligomers of poly (y-benzyl-L-glutamate) attached to polystyrene. He then performed chemical modifications on the pendant oligomers, showing that the functionalized oligomers can be used to separate racemic mixtures of amino acids. This would be a significant technological advance if these polymers could be extended to other chemical systems, particularly to drugs that do not form hydrogen-bonding interactions. The Organic Electronic Materials Group worked to develop the relationship between the chemical structure of starting polymers and their electrical properties. The materials produced include a new polymer phy(metacyclophane) that has an unusual π-overlap.

Perfect Crystal Project (1981-1986). The project goal was to grow perfect silicon (Si) and gallium arsenide (GaAs) crystals and to apply them to static induction control technologies. The static induction transistor (SIT) is a type of short-channel metal oxide semiconductor transistor (MOS) with unique electrical characteristics. The primary focus of the Fundamental Structure Group was low-power, high-speed Si MOS-type SITs and GaAs SITs. It developed and utilized photo-stimulated molecular layer epitaxy to grow GaAs/GaAlAs heterojunction devices with $f_c > 718$ gigahertz (GHz) (theoretical) and experimentally near 100 GHz. This group also obtained Si CMOS SIT integrated circuits with $E_{op} < 3$ femto Joule dissipating to 2 picowatts with < 0.1 picosecond switching speed. The Super High-Speed Element Group was successful in fabricating a double-gate static induction thyristor capable of turning off in 0.37 microseconds a 100 Å at 1kV load. The Perfect Crystal Group developed low-temperature (320 °C to 500 °C) photo-stimulated molecular layer epitaxy (PLME) of (100) GaAs. Most important was the perfecting of the arsenic pressure control Czrochralski method for the growth of bulk GaAs. This method produces < 500 defects per square centimeter for 610 °C, T_{As}, 624 °C. Special double-wall growth chambers were developed. The Optical Function Element Group fabricated 64- by 64-bit area sensors and 64- and 32-bit line sensors with excellent sensitivity, large dynamic range (10^5, an order of magnitude better than charge couple devices), small dark current, and good spectral response.

Nanomechanism Project (1985-1990). The purpose of this project was to explore nanometer (nm) measurements and control methods and to develop phase zone plates and multilayer X-ray mirrors for X-ray microscopy. The main activities of the Basic Analysis Group were the construction of three scanning tunneling microscopes for use with a scanning electron microscope, ultra-high vacuum combined with spectroscopy, and large-area (175 mm) very-large-scale integration (VLSI) testing. Activities also included the analysis of phase zone plates and multilayer X-ray mirrors. The panel considered this group to be the most likely to produce major scientific accomplishments. The Measurement and Control Group was investigating laser interferometry positioning to 10 nm and micromanipulators for 1- to 10-micrometer-sized objects. The goal of the Processing Group was to develop multilayer X-ray mirrors. Low-energy ion beam technology was used to create smooth surfaces. Both magnetron sputter and photo-stimulated chemical vapor deposition methods were being developed for depositing multilayer thin films.

Solid Surfaces Project (1985-1990). This project's purposes were: to explore novel methods to modify solid surfaces using chemical or photochemical reactions or physical deposition (molecular beam epitaxy [MBE]), and to study the structure and chemical and physical properties of these modified surfaces. The primary activity of the Basic Properties Group was to explore the physical properties of novel solid surfaces as well as transport, electronic, and magnetic properties of MBE-grown layered surfaces. The structure work was done at the photon factory using extended X-ray absorption fine structure, and the physical measurements were done in a new UHV-MBE system constructed for this purpose. The Reactivities Group was investigating chemical methods of growing novel layered surfaces using laser-induced photochemical reactions in a CVD mode. Other work focused on catalytic reactions of novel layered clay surfaces that form "house of cards" structures. The focus of the Functional Studies Group was to identify the chemical nature of and control the functional groups on semiconductor surfaces for better control in other CVD or MBE growth processes.

Quantum Magneto Flux Logic Project (1986-1991). The ultimate goal of this group was to demonstrate the feasibility of an ultra-fast computer using single quanta of magnetic flux as bits of information. This computer was expected to operate at speeds of 10 GHz with much lower power dissipation than conventional Josephson circuits. The Fundamental Properties Group was responsible for the fabrication and demonstration of the basic single flux quantum elements and of circuits made from those elements. In the Computer Architecture Group, a new architecture using the latching properties of the quantum flux parametron was being explored and would be first implemented using silicon technology. Because devices based on single flux quanta require a flux-free environment, the Magnetic Shield Group was exploring techniques to remove trapped flux from superconducting shields.

Bioholonics Project (1982-1987). Bioholonics is a kind of parallel processing with many units (holons) working synergistically. The project objective was to simulate and utilize the organization of information and processes found in biological systems to develop novel approaches to treatment of diseases such as cancer and atherosclerosis. The Self-Control Group developed improved approaches to cancer treatment using macrophage priming to produce endogenous tumor necrosis factor and to eliminate atherosclerotic lipid deposits in arteries. The Basic Design and System Construction Group worked on a system of simulation of visual interpretation of images, and the development of a small motor using actin and myosin with adenosine triphosphate as the energy for driving the motor. This field promises approaches to developing specialized treatments for human diseases by mobilizing the body's defense mechanisms to attack disease and restore homeostasis.

Bioinformation Transfer Project (1983-1988). The project goal was to examine the role of prostaglandins (PG) in the central nervous system. The Biotransmitters Group found that PGE2 induces secretion of catecholamines by the adrenal gland, which represents a new mechanism for biotransmitter release. This group also found a potentially important clinical application -- that PGD2 induces sleep in rhesus monkeys. The Neurotransmission Group determined the presence and distribution of various PG receptors in the brain using positive emission tomography scan techniques. The Neuropharmacology Group investigated the enzymology of the biosynthesis and interconversion of members of the PG family. It found that PG compounds, receptors, and biosynthetic pathways are distributed in body tissues such as the spleen, intestine, bone marrow, lung, and skin. This wide distribution may suggest other bioinformation transfer functions of PG, in addition to their possible role in the central nervous system.

Superbugs Project (1984-1989). The project objectives were to search for, analyze, and find practical applications by gene splicing enzymes from microorganisms that live in extreme environments. One group examined the basic physiology of the unusual organisms. A second group cloned the genes for some of the important enzymes and had them produced by more moderate microorganisms, such as *E. coli.* The third group used the cloned enzymes to develop important biotechnology applications, such as bioreactors and biosensors. A result of this work was the production and use of the enzyme cellulase in a detergent, *Attack,* which had annual sales of over 40 billion yen. Cyclodextrins that can be used to encapsulate various products had estimated annual sales of 2 billion yen.

Conclusions

The innovative ERATO program was intended to enhance basic research aimed at new technological advances. Equally important, it addressed the gap between basic research in the universities and applied research in industry.

At the time of this report, the program was funding a variety of projects; some were oriented toward applications, while others were more open-ended. The program tended to select high-risk areas that would become highly visible if successful. With about $30 million per year, ERATO was a small program focused on small projects directed toward long-range payoffs.

The overall scientific quality of the ERATO Program was high. Some successful projects were continued with other funding. In one case, the ERATO funding led to establishment of the group's reputation on an international scale. In another case, the ERATO funding enhanced a strong program that had been marginally funded.

The panel did not try to judge the sociological and political effects of the program. However, ERATO's funding was renewed for seven consecutive years, other institutions copied the ERATO funding model, and ERATO maintained a high overall quality of research. Despite these successes, the ERATO Program was not widely known in Japan's science community.

II. Information and Communication Technology

DISPLAY TECHNOLOGIES IN JAPAN

June 1992

Lawrence E. Tannas, Jr., Tannas Electronics (Panel Cochair)

William E. Glenn, Florida Atlantic University (Panel Cochair)

Thomas Credelle, Apple Computer

J. William Doane, Kent State University

Arthur H. Firester, David Sarnoff Research Center

Malcom Thompson, Xerox Corporation

BACKGROUND

The Japanese have recognized that as we enter the Information Age, both the computer industry and the television industry will need new display technology. The introduction of the laptop computer has created a need for a thin panel display with good readability and low power consumption. Television is entering a new era of high definition television (HDTV). The Japanese have recognized that new display technologies are critical to making their electronic products highly competitive in the world market.

SUMMARY

Japanese-U.S. Comparison

The panel feels that U.S. display technology is competitive in some areas and superior in others. However, without the long-term investment in manufacturing facilities and the resolve to lower manufacturing costs by addressing both the computer and consumer markets, the U.S. will not be able to profit from its investment in display research. Japan is currently expanding its lead in product development, is dominating in investment and manufacturing implementation, and is competitive in basic research (and gaining). The relative status of the U.S. and Japan in flat panel displays is shown in Figure 1.

	Research	Development	Production	Max Size
Passive LCD				
Super Twist	+ ↗	+ ↗	+ ↗	17" Japan
Ferro-LCD	○ ↗	+ ↗	+ ↗*	15" Japan
ECB	+ ↗	+ ↗	+ ↗*	14" Japan
Active LCD				
Metal-Insulator-Metal	+ ↗	+ ↗	+ ↗	13" Japan
Amorphous-Si TFT	○ →	+ ↗	+ ↗	15" Japan
Poly-Si TFT (Low Temp)	— ?	— →	NONE	NOT KNOWN
Poly-Si TFT (Hi Temp)	— ?	○ ↗	+ ↗	10" Japan
Polymer Dispersed	— →	○ ↗	NONE	NONE
Emitters				
Electroluminescent	+ →	— ↘	— ↘	18" USA
DC Plasma Display	+ ↗	+ ↗	+ ↗	33" Japan
AC Plasma Display	○ ↗	○ ↗	+ ↗	31" Japan

+ = Japan ahead ↗ = Japan gaining ground

JUNE 1992 * The Japanese have announced production for late 1992

Figure 1. Comparison of U.S. and Japan in Display Technologies

Liquid Crystal Displays

By the mid-1980s, it was becoming obvious to displays industry experts that the Japanese displays industry was beginning to make significant breakthroughs in technical developments and in the manufacturing of liquid crystal displays (LCDs). In Japan, the stage is nearly complete for the production of flat panel displays (FPDs) through the end of the 1990s. The LC FPD industry is now orders of magnitude ahead of the other FPD technologies. The research, development, and production activities in Japan are so focused on LCD technology that funding for advancing electroluminescent (EL), plasma, and other FPD technologies is diminishing. In Japan, LCDs are perceived as clearly being the leading edge technology, but the cost and complexity of the new amorphous silicon (a-Si) LCD factory are so extensive that the larger machines of the next generation will not be attempted until the present generation of machines have completely proven themselves and been paid for.

Liquid Crystal Materials

Low-molecular weight nematic liquid crystalline materials for twisted nematic (TN), super-twisted nematic (STN), and ECB displays are well developed, and European nematics materials producers have established joint ventures in Japan to tailor-make mixtures for display manufacturers.

Most improvements in TN and STN displays are expected to come from materials such as retardation films and improved alignment layers. Japanese companies are the only suppliers of retardation films. Other improvements are expected to come from the synthesis and design of new low-molecular weight LC materials for ferroelectric chiral smectic (FLC) displays. Also, several Japanese companies are studying new molecular forms. Gray scale was perceived to be a major problem by most of the Japanese companies.

Most Japanese companies had research programs on polymer-dispersed liquid crystals (PDLC) materials, and there appeared to be interest in these materials for projection applications. Advances are also being made in the development of blue and white EL phosphors. In the plasma display panels (PDPs), new designs and success in discharge cell structure are expected to give new focus to materials research.

University researchers in Japan are more aware of display materials problems and industrial needs than are their counterparts in the United States and Europe. University research is more basic in general, and basic research on liquid crystals is more driven by display technology than in the U.S. and Europe.

Active Matrix Liquid Crystal Technology

Over the past few years, progress in active matrix LC (AMLC) technology has been spectacular. Remaining questions are how low the cost can be, how fast they will penetrate the market, and how good their ultimate performance will be.

Manufacturing issues have become the prime focus of research and development. Research is continuing on low-temperature polysilicon. The market niche that drives polysilicon currently is for view finders and projection light valves.

The main thrust in AMLC technology is directed towards developing cost-effective manufacturing of amorphous-silicon active matrix liquid crystal displays (AMLCDs). In these applications, the ability to integrate the drive electronics onto the AM substrate provides a significant, and at times enabling advantage. Seiko-Epson and Toshiba continue to develop metal-insulator-metal (MIM) technologies, but MIMs are expected to only serve limited applications in which cost is more severely constrained than performance.

There is intense competition for market share, because many major Japanese corporations view this area as a strategic long-term investment.

Passive Matrix Liquid Crystal Displays

Passive matrix LCDs dominate the flat-panel display business today, and will continue to dominate it, at least in unit sales, for the next five years. The passive matrix LCDs covered in this panel's report are twisted nematic, supertwisted nematic, vertically-aligned nematic (VAN), and ferroelectric.

Film-compensated STN (FSTN) LCDs have enabled a new industry (portable and notebook computers), and are also used widely in Japan in word processors. Color FSTN LCDs will continue to improve and will be introduced to the market in significant numbers in 1992-93. FSTN LCDs have not reached their full potential, and improvements are expected in several areas in the next few years.

VAN LCDs have made impressive gains but probably will be limited to niche markets because of their slow response time and low optical efficiency. Ferroelectric LCDs are under active development at a few laboratories, but only Canon has announced production plans. If Canon has solved the manufacturing problems, then these displays will give competition to active matrix LCDs, especially in the larger sizes.

Projection Displays

In Japan, much of the new display development has been motivated by the high-definition television market. At this time the only feasible options seem to be either direct-view large panels -- such as PDPs or AMLCD panels -- or projectors. In the short term, only projectors seem to have the cost and performance characteristics for consumer HDTV displays. For large screen displays, cathode-ray tube (CRT) projectors with good performance have been produced.

Currently, university laboratories in both the U.S. and Japan are doing competitive basic work. In both countries, a large part of the basic research is funded by governmental agencies. Although research in CRT projectors continues, the major effort seems to have shifted to AMLCD light-valve projectors. These projectors provide images with excellent quality and have a number of cost and performance advantages.

Efforts at this time seem to be concentrated on reducing cost and increasing the yield of projectors of the current design in an effort to have consumer-quality projectors available by 1995. The major thrust of the effort seemed to be to concentrate on products using current system designs.

Future Trends

Future display needs will probably be met with a combination of types. For small displays -- from 14- to 16-inch diagonals and eventually up to 20 inches -- it is expected that LCD panels will dominate for the foreseeable future. At present this market consists primarily of passive matrix LCDs, but higher performance AMLCD panels are rapidly expanding their share of the market. It is expected that CRTs will still dominate the market for 20- to 30-inches sizes. For displays larger than this, light-valve projectors using AMLCD panels are thought to be the near-term solution. In the longer term, NHK and several others expect plasma panels to be used for the long-sought-after "hang-on-the-wall" display.

DATABASE USE AND TECHNOLOGY IN JAPAN

April 1992

Gio Wiederhold, Stanford University (Panel Chair)

David Beech, Oracle Corporation

Charles Bourne, DIALOG Information Services

Nick Farmer, Chemical Abstracts Service

Sushil Jajodia, George Mason University

David Kahaner, Office of Naval Research

Toshi Minoura, Oregon State University

Diane Smith, Xerox Advance Information Technology

John Miles Smith, Digital Equipment Corporation

BACKGROUND AND GENERAL CONCLUSIONS

This report presents the findings of a group of database experts, sponsored by JTEC, based on an intensive study trip to Japan during March 1991. Academic, industrial, and governmental sites were visited. The primary findings are that Japan is inadequately supporting its academic research establishment, that industry is making progress in key areas, and that both academic and industrial researchers are well aware of current domestic and foreign technology. Information sharing between industry and academia is effectively supported by governmental sponsorship of joint planning and review activities, and enhances technology transfer. In two key areas, multimedia and object-oriented databases, export of Japanese database products, typically integrated into larger systems, is on the horizon.

Database research in industry relies heavily on publications from the U.S. and Europe for conceptual input. The researchers are well-read and often well connected with foreign academic sources; thus they provide an important path for technology transfer.

Role of the Japanese Government

The Japanese government, overall, seems to have less influence on research directions than is perceived by outsiders, although it does appear that the Japanese government has done more than most governments to further database use and technology. Academic researchers have considerable flexibility in choosing the directions for government-sponsored research. The level of government funding for industrial laboratories is relatively low, and does not influence market-driven priorities. However, these projects do require regular meetings of academic, government, and industrial researchers, increasing mutual awareness, understanding, and enhancing technology transfer.

Driving Force: The Japanese Electronics Industry

An important driving mechanism in database development is the Japanese capability in the area of developing electronic products. High-quality image acquisition, transmission, storage, display, and digitized voice data are emphasized. The panel concluded that purchasers of systems with multimedia requirements will, with Japanese image-processing hardware, acquire Japanese database software. This field is likely to grow rapidly. Computer-assisted design (CAD), computer-assisted engineering (CAE), and other application areas that are critically dependent on graphics will be the initial applications of this technology.

Hardware

Japanese hardware for computer systems is roughly equivalent to U.S. systems, except again in the areas of multimedia support and optical mass storage, where the Japanese have a substantial advantage. Parallel architecture and database accelerator schemes are of active interest in Japan.

Hardware support for database systems is provided equally well by Japanese and foreign companies. Sony is an important supplier of workstations, but U.S. companies such as SUN Microsystems are also well represented. Japanese mainframe-based database systems are similar to their U.S. counterparts, but this market shows less growth and is less fluid.

Relevant research on topics such as database accelerators is being pursued. This work can be seen as a specialization of research into parallel computation, which is pursued by computer researchers everywhere with equal intensity. The payoff is likely to come as demands on database computation increase.

The Database Industry in Japan

The JTEC study also surveyed the industry that maintains databases and sells information retrieved from these databases. In this area, Japanese databases provide useful service internally, but are not in a position to export their services. There is substantial use in Japan of Western databases, both via U.S. and European vendors and via Japanese resellers. Some internal developments are oriented towards providing image data as well. Providing such services on an international scale awaits high capacity communication lines and acceptance standards. In this area the relative situation seems stable.

While Japan is not viewed today as a world-level player in the database area, the infrastructure is in place for Japan to make important contributions in areas where there is high growth potential and linkage with consumer hardware.

Qualitative Comparisons Between the U.S. and Japan

The panel has prepared a qualitative comparison of the present status and trends in database systems research in the U.S. and Japan. The subject matter covered by the panel was divided into seven subtopics: mainframes, hardware-PC, workstation-servers, storage, database content, database management systems, and new database technologies. (See Figs. 2-8).

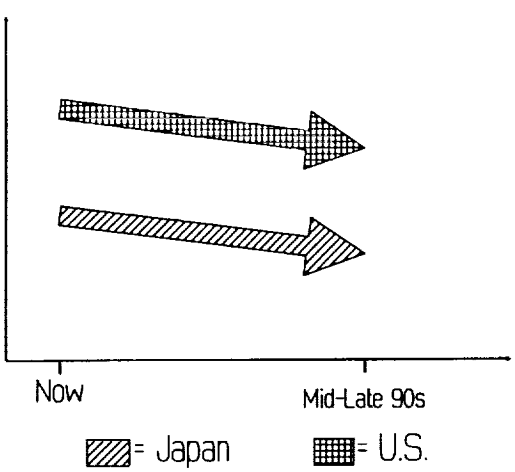

Figure 2. Mainframes

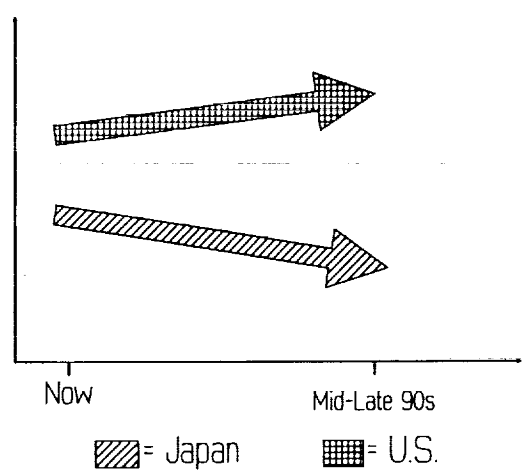

Figure 3. Hardware - PC

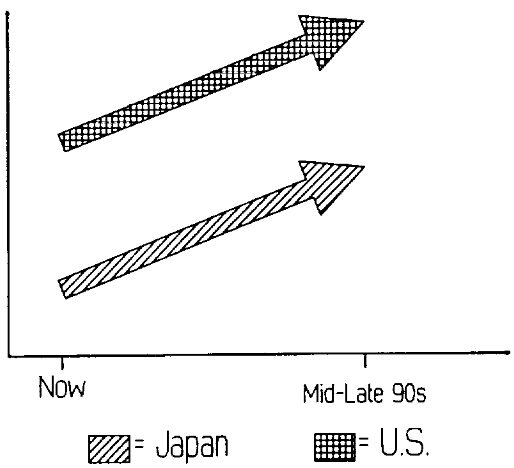

Figure 4. Workstations - Servers

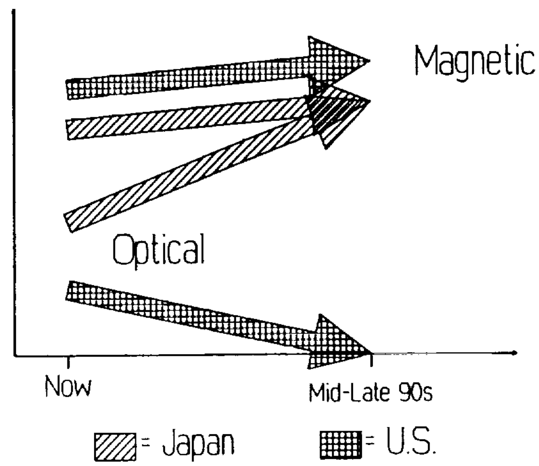

Figure 5. Storage

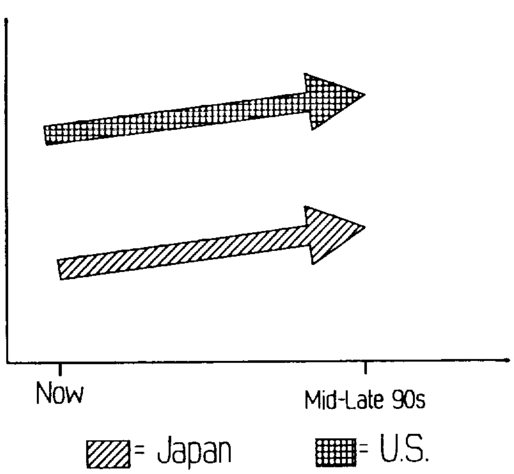

Figure 6. Database Content

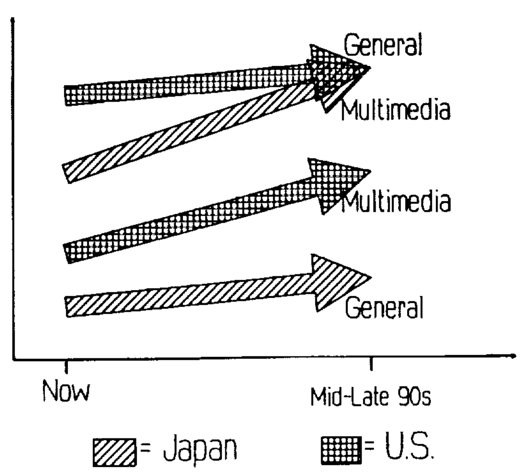

Figure 7. DBMSs

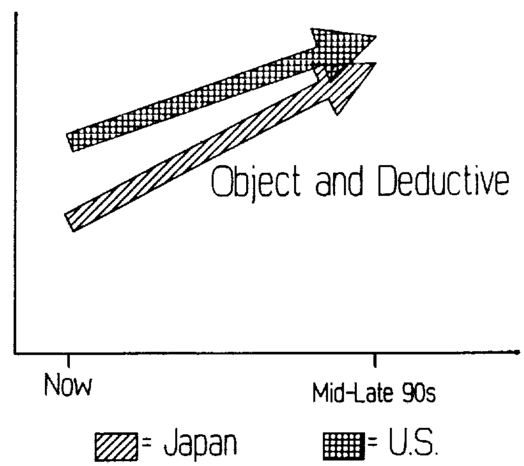

Figure 8. New DB Technologies

MACHINE TRANSLATION IN JAPAN

January 1992

Jaime G. Carbonell, Carnegie Mellon University (Panel Chair)

Elaine Rich, MCC (Panel Cochair)

David Johnson, IBM

Masaru Tomita, Carnegie Mellon University

Muriel Vasconcellos, Pan American Health Organization

Yorick Wilks, New Mexico State University

BACKGROUND

The goal of the JTEC report on machine translation is to provide an overview of the state of the art of machine translation (MT) in Japan, and to compare Japanese and U.S. technology in this area. The term "machine translation" as used here includes both the science and technology required for automating the translation of text from one human language to another.

SUMMARY

In Japan, machine translation is viewed as an important strategic technology that is expected to play a key role in Japan's increasing participation in the world economy. As a result, several of Japan's largest industrial companies are developing MT systems, and many are already marketing their systems commercially. There is also an active MT and natural language processing (NLP) research community at some of the major universities and government/industrial consortia.

The principal use for MT today is in translating technical documentation for products to be sold abroad. The volume is still relatively small but appears to be growing steadily. There is also an increasing use of MT embedded in other applications, such as database retrieval systems, electronic mail, and (in the prototype stage) speech-to-speech translation systems.

Users have reported varying degrees of success with MT. While a few users have actually experienced lower productivity using MT compared to conventional approaches, productivity gains of 30 percent appear average. Higher numbers are typical for restricted domains and lower numbers for broader domains. Most uses of MT require some human pre- or post-editing to produce acceptable quality translations.

SPECIFIC R&D COMPARISONS

In both the U.S. and Japan, total funding for MT appears to be on a gradual but steady rise. Japanese commitment to MT is greater than that of the U.S., though the U.S. commitment is by no means insignificant.

In both Japanese and U.S. markets, MT is gaining gradual acceptance (Fig. 9), with Japan having and maintaining a lead. The same situation and trends are present for the integration of MT systems into other text processing software (Fig. 10).

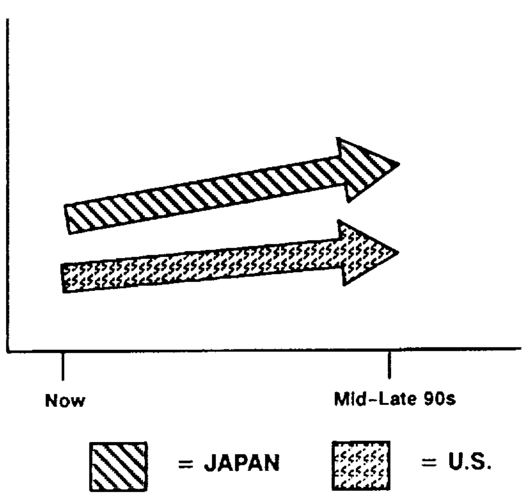

Figure 9. Acceptance of MT

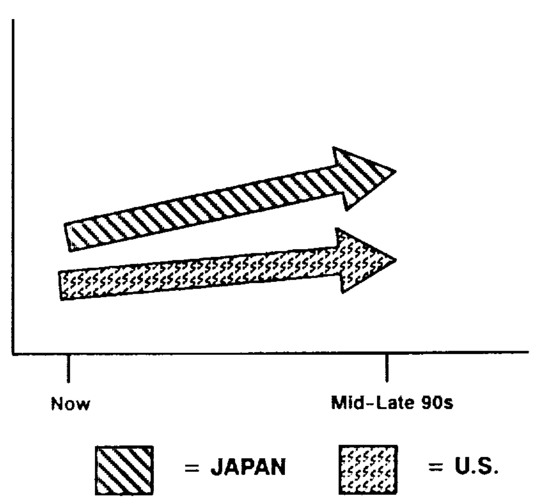

Figure 10. Integration of MT

Improved accuracy appears to be the single most important factor in determining how widely MT will be accepted. Japanese and U.S. efforts are expected to show steady improvement in accuracy between now and the mid- to late-1990s (Fig. 11).

MT requires multiple knowledge sources, which are large and expensive to build and maintain. Consequently, they are valued resources in MT research and are even more important in successful MT system deployment. Japan is currently leading the U.S. in private knowledge sources, and this lead may be widening (Fig. 12).

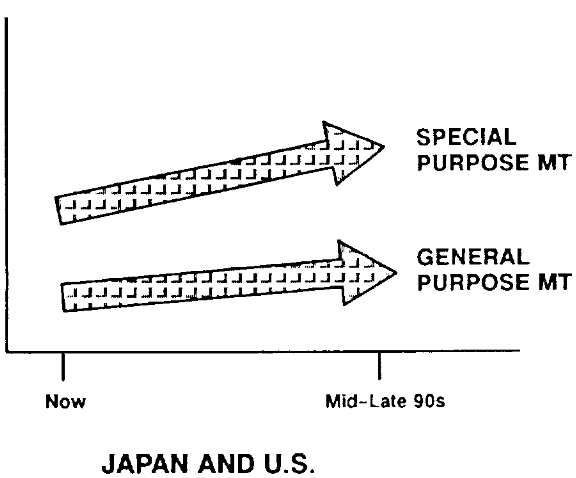

Figure 11. Accuracy of MT

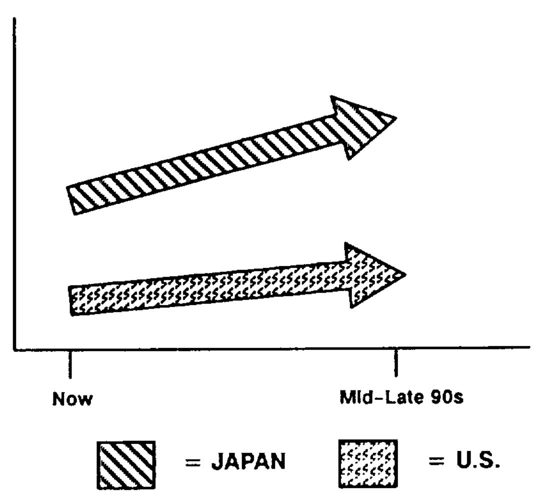

Figure 12. Private Knowledge Sources

Although Japan also leads in shared knowledge bases (Fig. 13), the gap may narrow assuming continued funding from the Defense Advanced Research Projects Agency (DARPA) and other U.S. government agencies that are targeting some funds specifically at building shareable knowledge sources.

The basic science and technology underlying MT is natural language processing (or computational linguistics), which is the study of computer processing of language. Traditionally the U.S. has been a bastion of scientific research in this area, but research funds in the U.S. have been decreasing. Funding in Japan and Europe has been increasing and will surpass the U.S. level, if it has not already done so. Thus, the U.S. risks being surpassed (Fig. 14) in the one area where it has traditionally led: computational linguistics, both the basic theory and computational methods.

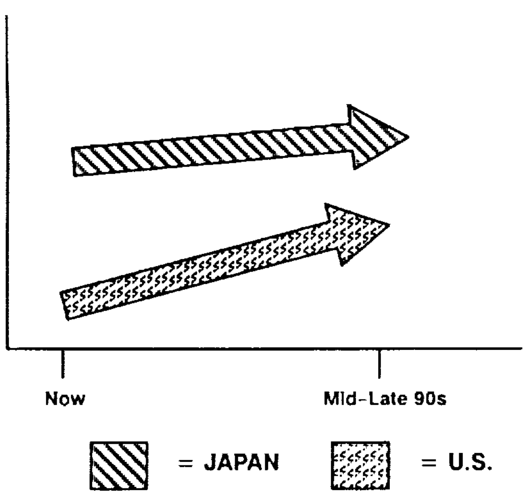

Figure 13. Shared Knowledge Sources

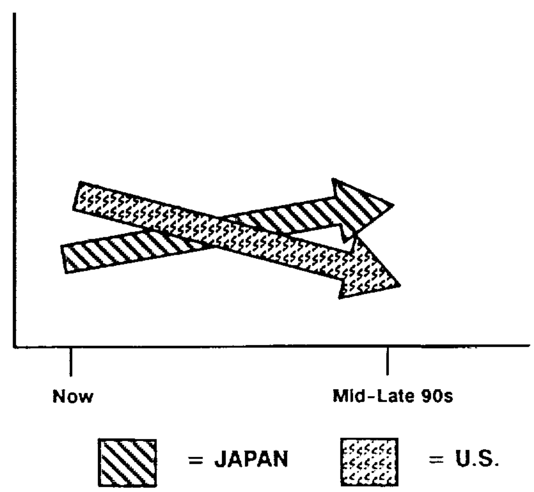

Figure 14. Funding for Basic Research in Natural Language Processing

The U.S. is ahead of Japan in some areas. For example, the U.S. currently leads Japan in technological diversity, that is, the variety of approaches to MT (Fig. 15) and linguistic diversity, that is, the number of languages being developed (Fig. 16). Present trends indicate that although the U.S. will maintain its lead in technical diversity, the gap will narrow in linguistic diversity.

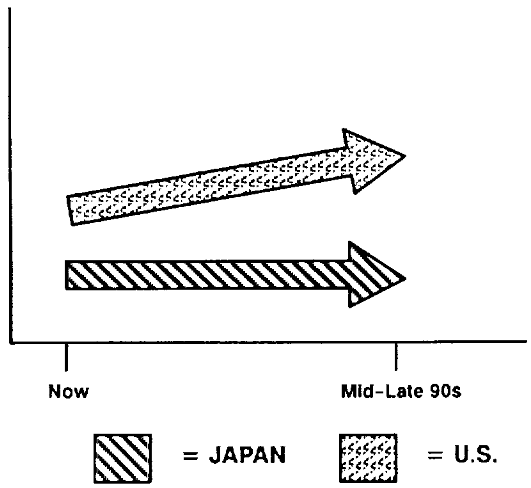

Figure 15. Technological Diversity

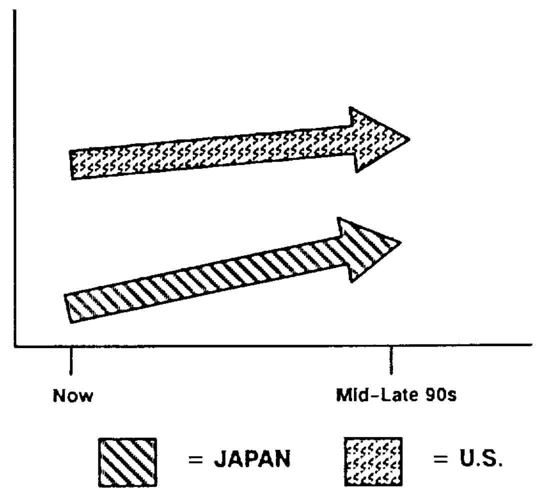

Figure 16. Linguistic Diversity

The U.S. also maintains a lead in other related research areas. For example, the U.S. leads in speech recognition technology (Fig. 17), but both the U.S. and Japan are working on the early integration of speech technology into speech-to-speech MT. The U.S. also has a narrow lead in natural language processing technologies (Fig. 18) such as automatic extraction of knowledge from text, NLP-based human-computer interfaces, routing and classification of texts for assimilation, etc.

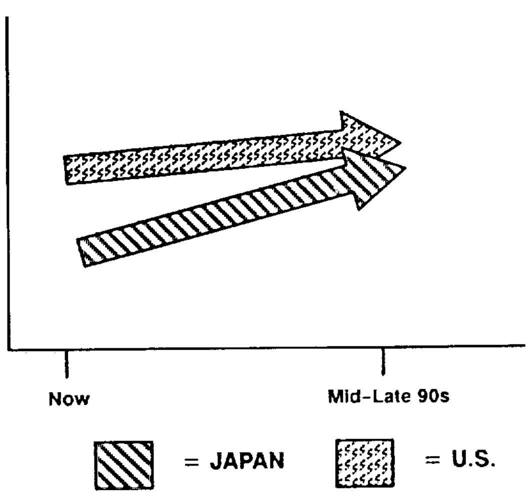

Figure 17. R&D in Speech Recognition and Speech-to-Speech MT

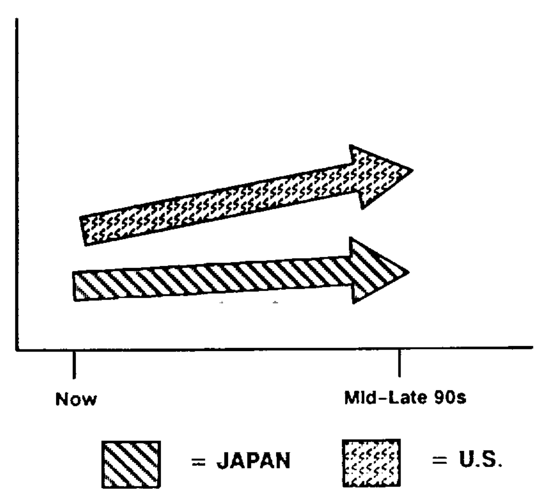

Figure 18. R&D in Other Natural Language Processing Technologies

THE FUTURE

A substantial amount of research is being conducted in Japan. Figure 19 shows that funding for MT R&D in Japan is substantially higher than in the U.S., although U.S. funding is expected to increase. New Japanese corporate funding is more focused on productivity and commercialization. Figure 20 indicates the expected increase in commercial MT in Japan in response to this trend.

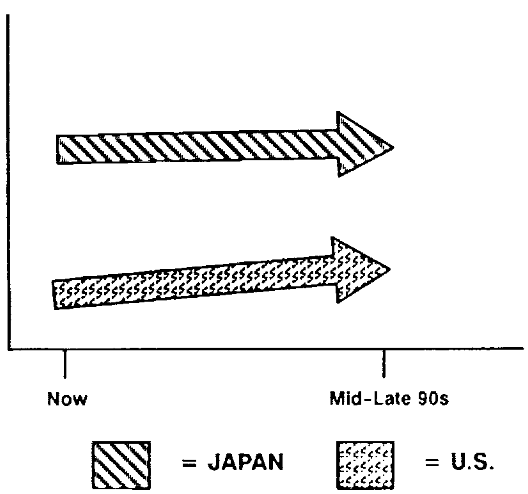

Figure 19. Funding for R&D in MT Technology

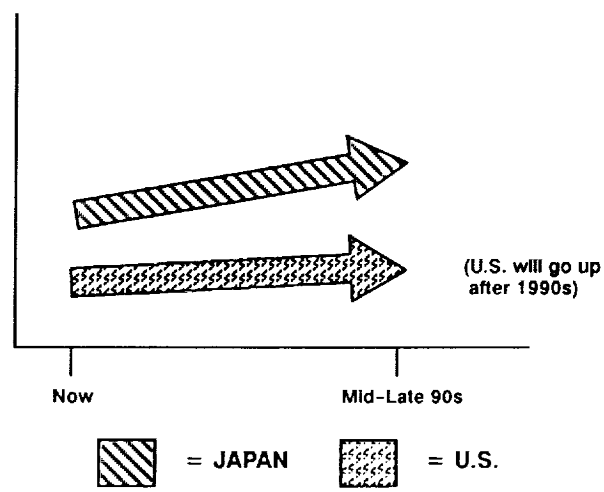

Figure 20. Commercial Use of MT

While there are unlikely to be any major technology breakthroughs in MT during the next five years, steady progress is expected, especially in the quality of machine translations. As knowledge bases grow in quantity, quality, and comprehensiveness, the sharing of these intellectual properties will become more common. User interfaces are also improving, partially as a result of the positive feedback from the growing community of MT system users. As a result, the Japanese fully expect to see a return on the substantial investment that they have made and are continuing to make in MT.

X-RAY LITHOGRAPHY IN JAPAN

October 1991

James T. Clemens, AT&T (Panel Chair)

Robert W. Hill, Hill Associates (Panel Cochair)

Franco Cerrina, University of Wisconsin

Gene E. Fuller, Texas Instruments

R. Fabian Pease, Stanford University

Henry I. Smith, MIT

BACKGROUND

The goal of the JTEC report on X-ray lithography, fully funded by the Office of Naval Research, is to provide a detailed appraisal of the technology, personnel commitments, and strategies for implementation in manufacturing of X-ray lithography in Japan.

Integrated circuits (semiconductors) are the key components of modern computers, communication systems, consumer electronics, and the new generations of smart machines and instruments. Microlithography is one of the most critical elements of the semiconductor manufacturing process because it determines the minimum feature size and the functional capabilities of the semiconductor. The quality of the microlithography process is critical in determining the yield and cost of semiconductors and hence the competitiveness of the electronics industry.

At present, all volume semiconductor manufacturing is done with optical UV (ultraviolet) projection lithography. X-ray lithography, however, holds the promise of providing higher yields in manufacturing semiconductors by virtue of enhanced process latitude, process robustness, and resolution.

SUMMARY

The major Japanese microelectronics firms have a broad, well-developed strategy for research and development of microlithography technology that includes UV, deep UV, X-ray proximity and projection, and electron-beam lithographies. They are investing in all of these alternatives. All of the manufacturers visited either had in-house X-ray programs, were members of the SORTEC X-ray consortium, or both. Their commitment to X-ray lithography was firm and appeared to be well balanced. In the U.S. there is limited interest from semiconductor manufacturers in X-ray technology, with the exception of AT&T, IBM, and Motorola.

Research Funding

Most funding for X-ray lithography efforts in Japan comes from individual industrial organizations. The Japanese government directly and indirectly has provided seed money to major research and development efforts. The government has funded roughly $70 million of the SORTEC development through MITI, and industry has funded $30 million. Japanese companies are making the major part of the X-ray investment in their own companies.

In the U.S., there has been a significant X-ray lithography program for over ten years at IBM. Motorola has recently joined the effort. Congress has provided money to DARPA for applied research and development on X-ray lithography in all sectors of the technical and industrial community. However, the U.S. industrial community has not been independently preparing itself for insertion of X-ray lithography into manufacturing.

Optical Lithography

The consensus among Japanese semiconductor manufacturers was that optical lithography would continue to evolve for advanced semiconductor manufacturing until the late 1990s, and that the potential switch to X-ray lithography would probably occur when the minimum critical dimension reached 0.25 micron or less. While their first choice for 256 megabit dynamic random access memory (DRAM) was optical, they were prepared to use X-ray technology for manufacturing. Although they recognized potential of higher yield and lower manufacturing costs with X-ray, manufacturers will not change technology until absolutely necessary. This same viewpoint prevails in the United States and in Europe.

Synchrotrons

There were many large efforts in Japan to develop synchrotron-based lithography systems because they are bright, collimated sources. Smaller laser and gas plasma sources, while more desirable from a granularity standpoint, were not visible or discussed in detail. X-ray projection projects exist; they were mentioned at several companies but not extensively discussed.

The size, cost, and configurational aspects of synchrotron-based X-ray lithography did not appear to be serious issues in Japan with the DRAM manufacturers. Their view was that if X-ray lithography were used, it would be for large-volume manufacturing, which would require multiple synchrotron facilities. Cost has been a major issue with the U.S. and European manufacturers since their volume semiconductor production has not been DRAM-based, their companies are smaller, and many are not using the leading edge of microlithography technology. The initial investment is beyond the means of most of these manufacturers; only IBM, AT&T, and Motorola have major active internal X-ray programs. Also, in the U.S. several synchrotrons originally developed for other purposes are being used in part for X-ray lithography R&D.

DARPA is administering a program sponsored and financed by Congress that attempts to overcome some of these difficulties by helping to build the infrastructure necessary for X-ray lithography. DARPA is expanding that program to support other lithographic alternatives.

Other Research

Development of X-ray mask technology, exposure systems, and resists has been pursued vigorously in Japan, as has integration of the total system.

There appeared to be a consensus that materials for X-ray masks were adequate. The Japanese were using silicon nitride membranes with tantalum absorber mask technology licensed from NTT. They were researching silicon carbide membrane and tungsten absorber materials, and planned to research diamond membranes.

The major mask concern was 1X electron-beam mask patterning, specifically errors in feature placement and dimension control. There was no work on mask inspection and repair underway; the Japanese believe these tools will be available from domestic or overseas sources when required.

Several independent efforts were being pursued on exposure system aligners, with critical elements under development. Heterodyne interferometric alignment techniques were favored for alignment; these were more advanced in concept than current U.S. or European projects.

With respect to fundamental understanding of the science of X-ray lithography, the Japanese and the U.S. technical communities were on a par. The trend, however, was for the Japanese to pull ahead of the U.S. due to a higher level of funding and staffing, particularly at the company level.

If X-ray lithography becomes necessary for producing the next generation of semiconductors, Japanese industry will be in an excellent position to maintain or increase its market share in semiconductors and the advanced systems dependent on them.

HIGH DEFINITION SYSTEMS IN JAPAN

February 1991

Richard J. Elkus, Jr., Prometrix Corporation (Panel Chair)

Robert B. Cohen, Consultant

Birney D. Dayton, NVISION

David G. Messerschmitt, University of California

William F. Schreiber, Massachusetts Institute of Technology

Lawrence E. Tannas, Jr., Consultant

SUMMARY

"High definition" describes new products or systems whose value resides in their ability to process greatly increased amounts of audio and video information. Processing of information is fundamental to the infrastructure of electronics, telecommunication, and media markets. The panel's goal was to study technological developments in Japan pertaining to high definition systems. A brochure from Japan's Ministry of Posts and Telecommunications described high definition television as "the cornerstone of the information age," which indicated a dedication to the concept of HDTV in Japan. The purpose of this dedication seemed to be to focus the Japanese electronics industry on a problem that, when solved, might have advanced the state of the electronics manufacturing art in Japan a generation beyond that of the rest of the world.

The Japanese manufacturers the panel visited indicated that near-term applications of HDTV technology that would justify their investment were in information systems and industrial applications. Public relations literature made clear the long-term focus of Japanese electronic companies on the increasing use of speech, image, and video in all phases of information systems and illustrated a combined vision of and commitment to a new age of information technology.

The panel report does not address the new digital approaches to HDTV, which were publicized after the panel had completed its work.

HDTV and Its Signal Processing

High definition systems require a lot of bandwidth to store and transmit video. The two major technological components of high definition systems (HDS) are digital signal processing (DSP) for compression and quality enhancement, and high-resolution displays. An example is the Japanese MUSE system, which is analog transmitted by satellite but uses large doses of DSP in the transmitter and receiver to compress the bandwidth. In 1989, six Japanese manufacturers were cooperating with the public broadcasting organization NHK on a reduced-cost MUSE receiver that required development of thirty separate application-specific integrated circuits. The panel saw several projects engaged in compression of digitally-encoded HDTV.

The importance of these DSP developments transcend their near-term application to HDTV. For example, the U.S. was strong in DSP, which was a technology driver because it required high arithmetic processing rates that often exceeded even those of supercomputers. DSP was also a key component of many military and commercial systems. HDS requires some of the highest processing rates of any DSP applications and, hence, drove Japanese manufacturers toward very advanced electronics technologies and advanced architectures such as multiprocessor DSP. The Japanese expect HDS to be an element of many future commercial applications, such as multimedia applications in computing and new products in medicine, manufacturing, publishing, filmmaking, education, and telecommunications. Japanese manufacturers would be well positioned in these markets, given their DSP and display capabilities.

A twenty-year research effort coordinated and facilitated by NHK led Japanese manufacturers to world leadership in HDTV technology. Participating Japanese manufacturers could justify their investment knowing that, with NHK coordinating, their components would fit into the larger system. NHK's coordination was much more important than any public-sector monetary support it offered. This illustrated one way to pursue a research effort for a system so complex that it transcends the capabilities of any single manufacturer.

Evolution of Displays in Japan

High-quality, high-resolution displays are critical to the success of HDTV. At the time of the panel report, one technical limitation of HDTV lay in the display. The five problems were to: (a) generate the resolution in one continuous image plane; (b) make the image plane large to create realism; (c) change images to show real-time dynamics; (d) create the image in color; and (e) combine all these features at a consumer market cost with acceptable weight, power, and volume characteristics. Many display panels could meet some of these requirements. For example, ac plasma panels could be made with high resolution, but not simultaneously in color or at acceptable cost. Japanese industry was attempting to develop a large ac plasma panel and active matrix liquid crystal flat-panel, direct-view HDTV display prototype by 1995. U.S. industry was reportedly no longer attempting to develop an NTSC TV flat-panel display to hang on the wall. HDTV displays available in Japan had come about from improvements in cathode ray tube (CRT) and projection technologies. The second contender for consumer HDTV displays that the panel identified was the LCD light valve using three active-matrix liquid crystal cells. It was not yet clear whether this technology could compete with CRT projectors.

High Definition Standards and Equipment Development in Japan

JTEC panelists were often told that the Japanese could build to any standard within one or two years of learning about it. The process of developing standards in Japan was similar in some respects to that in the U.S., but the panel also found differences. Japanese companies had been participating in the U.S. process. This participation had been made possible because many Japanese could speak English, the diverse nature of U.S. culture made it very easy to find proxies, and Japanese companies had a strong export orientation. By contrast, U.S. companies were usually distant from the standards process in Japan.

Numerous standards for different HDTV (1125/60) equipment had been developed or were under development in Japan. Work had been done on a variety of television standards of intermediate resolution (greater than NTSC but less than true HDTV) under the rubric "EDTV," or enhanced definition TV. Significant progress had also been made in standards setting for components, such as HDTV semiconductors and displays, and for end-use products, such as studio HDTV equipment, industrial products, and consumer products.

A rapid cycle of standardization, manufacture, improvement, adaptation, and restandardization characterized Japan's standards process. Japanese companies were willing to adopt standards from elsewhere, adapting them to suit their changing needs. By contrast, the standards generation process in the U.S. was seen as slow.

Japanese High Definition Television Systems

That HDTV existed as a standards issue in the U.S. was largely due to the development of a system and equipment in Japan, and to Japanese efforts to have their system adopted worldwide. NHK began HDTV development in 1970. The plan was to implement HDTV in Japan as an entirely new service, delivered to viewers by direct-broadcast satellites (DBS) to supplement the over-the-air (terrestrial) system that would continue to use NTSC, the color standard used in both the U.S. and Japan. Scanning standards were chosen with the intention of making the picture quality comparable to that of 35-mm motion pictures. Since standard satellite transponder channels were inadequate for this studio system, the MUSE transmission system was developed to allow a compressed version of the signal to be transmitted in a normal satellite channel. System and equipment developments were paralleled by efforts to have the studio system adopted as an international standard for program production and international exchange. However, the system was not optimum for cable or terrestrial broadcasting. U.S. industry may learn from the Japanese experience in HDTV development and devise a system suitable to U.S. needs.

Japan's Public Policy Initiatives in Support of High Definition Systems

Japan's leading electronics corporations and the Japanese government have invested substantially in R&D to commercialize HDS and HDTV. Many Japanese leaders seemed to view HDTV as the center of a move to a vastly different Japanese economy that would offer huge benefits in growth and consumption. They also appeared to believe that government financing for the early stages of HDS development was important to reduce corporate risk and ensure that private funds would be forthcoming for the first stages of commercialization. Government funds also supported the development of key HDTV component technologies.

Sales to industrial customers were expected to support the growth of the new HDS market initially. Corporations would develop controls for design, engineering, and production or service-delivery processes, advances that would create new market opportunities for these firms. Development of HDTV was likely to enhance the interdependency of some of the most dynamic parts of Japanese industry and promote further vertical integration of the largest Japanese electronics firms.

The strong base that Japan's major corporations had in the consumer electronics industry facilitated their move into HDS. By playing a major role in the consumer electronics and semiconductor industries, these firms had a greater ability to benefit from economies of scale in developing new display, semiconductor, and processor products. The Japanese recognized the need for government-promoted R&D in high-risk areas such as large flat-panel displays. Therefore, they created new business-government entities, including the Key Technology Center and an HDTV leasing corporation. The Japanese also expected a significant boost in demand for semiconductors from HDS development.

High Definition Products and Systems: The Strategy of Leverage

To Japanese businessmen, strategy is everything. Every person, business, and industry must have a goal and a strategy by which to achieve it. Because resources are usually scarce, the successful Japanese plan includes the concept of leverage. Some markets are considered more strategic than others. By targeting strategic markets, an infrastructure can be built that ensures a solid basis for economic expansion. However, the leverage is not based simply on the importance of one market over another, but rather on the assumption that, as they develop, strategic markets will become interrelated and interdependent, with the whole becoming substantially larger than the sum of its parts. Therefore, coordination of strategy and direction is essential -- a point that is fundamental to the strategy of product and market development in Japan. It is based on the concept that if the development of a product or market is pushed to its logical extreme, it becomes related to other products and markets. Thus, Japanese business strategy does not reject a product or market on the basis of profit potential, but rather assumes that every product becomes the basis for another, and every technology becomes the stepping-stone for the next. The resulting efficiencies of scale are enormous.

The market for high definition products and systems can help push the markets for electronics products, telecommunication services, and software (including mass media) to their logical extreme. The Japanese expressed the view that, perhaps by the year 2000, the requirements and possibilities created by improving the technology to rapidly process large amounts of audiovisual information would force a confluence of these three end-use markets into a single information systems market. They expected that the information systems market would grow to represent 33 percent of all capital investment, 44 percent of all new jobs, and 22 percent of all economic growth.

The Japanese felt that in the future information age, any nation without a proprietary position in or reliable strategic access to each of the market segments within electronics, the media (including software and mass media), and telecommunication services would be at a significant competitive disadvantage. This concept was in part the basis for the accelerated development in Japan of high definition products and systems, and underscored the significance of high definition technology and its effect on all parts of the industrial structure of Japan.

ADVANCED COMPUTING IN JAPAN

October 1990

Michael A. Harrison, University of California, Berkeley (Panel Chair)

Edward F. Hayes, Rice University

James D. Meindl, Rensselaer Polytechnic Institute

James H. Morris, Carnegie Mellon University

Daniel P. Siewiorek, Carnegie Mellon University

Robert M. White, Department of Commerce

SUMMARY

To assess Japanese technology in advanced computing, the panel divided the subject into electronic components, data storage, computer architecture, software, computer/human interface and multimedia, and supercomputers. The panel obtained a baseline of U.S. accomplishments in these areas by reviewing literature, attending conferences, visiting laboratories, and discussing the subject with specialists. The panel then spent a week in Japan visiting five university sites, sixteen industrial sites, one consulting company, and nine government laboratories.

The Technical Bottom Line

Table 4 summarizes the positions of the U.S. and Japan in advanced computing.

Japan has made a significant long-term commitment to information technology, from research through commercialization. Policymakers, aware that Japan would have difficulty being self-sufficient in food and in energy, decided as early as 1955 to meet international competition and make international contributions by cultivating information as a resource. Japan would draw on a highly educated and motivated labor force to promote information-related, knowledge-intensive industries. Japan has implemented this goal through national programs. Industrial strategies have been coordinated, and MITI introduced a series of multi-year plans devoted to achieving excellence in information technology.

Table 4
Japan's Position vs. U.S.: Advanced Computing
(See Key, p. xvii)

Area	Position	Rate of Change
Electronic components	+	>>
Data storage	0	>>
Computer architecture	-	>
Software	-	=
Scientific calculations and supercomputers	0	>
Computer/human interface	-	<
Multimedia	+	>

Japan's success in information technology is due in large part to its support of industries in the allied technologies -- advanced semiconductors, chip-making technology, data storage devices, and so forth.

Japan's success in the computer industries has led to significant market share; the profits have been reinvested in R&D, and Japanese capital expenditures have remained high. Thus the panel expected that the Japanese competitive position would remain strong for at least the next five years. Whether the U.S. could maintain its competitive position would depend on whether the U.S. was willing to match Japan's rate of investment.

The panel found Japan relatively weak in software but effective in software engineering. There was a serious shortage of talented software people who could be hired to work in the large, high-technology Japanese companies, partly because many young people chose to work for higher salaries in the financial community. Japan had nothing yet to compare with the strong community of creative and talented software people in the United States.

Japanese universities remained substantially weaker than their U.S. counterparts because they have had no large projects of the type supported by DARPA in the U.S. Japanese students graduated from universities with a good conceptual education. The companies then provided continuing education to train them in design, production, and so forth. Employer-sponsored continuing education in the U.S. was much less intensive and effective because of employee mobility.

A key theme in Japan was internationalization. Japanese companies were using the profits from their success in consumer electronics and other information industries to establish themselves in the U.S. and elsewhere. Individual companies were establishing R&D laboratories, product development laboratories, manufacturing facilities, and sales and distribution centers in the U.S.

Electronic Components

Table 5 shows Japan's position in electronics components by indicating the number of years Japan is ahead of (behind) the U.S. in various areas.

Table 5
Japan's Position vs. U.S.: Electronic Components

Device	Gap
SRAMS	= +2 years (high density)
DRAMS	= +3 years
NVRAMS	= 0 years
Gate arrays	= +1, 2 years (high density)
Microprocessors	= -2 years or more
Gallium arsenide	= +2 years
Packaging	No U.S. presence
Infrastructure	Eroding

The panel qualified the findings in Table 5 by noting that the interval between an R&D announcement and commercial production was typically smaller for U.S. companies than for their Japanese counterparts. This tended to exaggerate the gap between the countries' positions.

Data Storage

Table 6 compares the two countries in data storage. Most Japanese industrial research focused on near- to medium-term issues. The panel found an enormous amount of exploratory work being done on alloys for thin film media, tribology, magnetoresistive sensors, and so forth. By comparison, efforts in the U.S. appeared more fragmented but more adventurous -- for example, the holographic storage at MCC and attempts to exploit high-resolution scanning microscopy.

Table 6
Japan's Position vs. U.S.: Data Storage
(See Key p. xvii)

Area	Position	Rate of Change
Magnetic recording		
Heads	-	>
Media	-	>
Head-to-disk interface	0	=
System	-	>
Optical Recording		
Optical media	+	>
Lasers	+	>

Computer Architecture

The Japanese were experimenting with a vast number of computer architectures. Although their projects were based on American architectures, the gap between the American roots and the first Japanese project had narrowed from over a decade (i.e., from the American Illiac IV in the mid-1960s to the Japanese PAX in 1977) to less than a year (i.e., hardware simulation engines). Furthermore, although the number of advanced architectural projects was roughly equivalent in the U.S. and Japan, the sheer volume of Japanese projects initiated since 1980 was very impressive.

The U.S. was ahead of the Japanese in computer architecture. However, the Japanese were strong and growing stronger in hardware, prototyping, vector processing and pipeline design, dedicated hardware simulation architectures, multimedia workstations, and technology transfer between research and products.

Software

Except in software engineering, Japan has traditionally been weak in software, as is shown in Table 7. Although Japan has improved significantly in graphics, logic programming, and artificial intelligence applications, so has the rest of the international community. Ironically, the panel found that Japan had the lead in software engineering. U.S. researchers were conducting better software engineering research, but the Japanese were applying U.S. methods in a more disciplined fashion and achieving impressive results.

Table 7
Japan's Position vs. U.S.: Software
(See Key, p. xvii)

Area	Position
Programming languages	-
Operating systems	-
Artificial intelligence	-
Databases	-
Software engineering	+

Multimedia and Computer/Human Interfaces

The panel found the U.S. to be significantly ahead in computer/human interfaces, although the Japanese were beginning to concentrate in that area. In multimedia systems, the Japanese were ahead in hardware technology because of their significant consumer electronics industry; the U.S. was far ahead in software applications. Table 8 shows the panel's rankings in multimedia systems.

Table 8
Japan's Position vs. U.S.: Multimedia and Computer/Human Interfaces
(See Key, p. xvii)

Area	Position	Rate of Change
Computer-supported collaborative work	-	<<
Hypertext	-	<<
Electronic books	-	<
Multimedia		
Components	+	>
Workstations	0	>
MM Mail	-	<
User interfaces	-	<

Supercomputers

Table 9 records the panel's impressions of Japanese research in supercomputers. In most areas of computational science and engineering, the number of researchers in Japan was smaller than that in the U.S. by a considerable margin. However, the numbers were growing in each of the fields surveyed.

Table 9
Japan's Position vs. U.S.: Supercomputers
(See Key, p. xvii)

Area	Position	Rate of Change
Hardware	0	>
Architecture	-	>
Systems software	-	>
Monitoring tools	+	=
Vectorization	0	?

The panel predicted that for the next five years the U.S. would continue to have more researchers working in supercomputers and scientific calculations. If U.S. researchers continued to have access to enough state-of-the-art supercomputers, the U.S. would continue to provide leadership in developing new approaches, algorithms, and software.

Technical Summary

In the field of advanced computing in general, the panel found Japan to be ahead of the U.S. in basic building blocks such as chips and components. The U.S. predominated in software. However, revenues for software development could not be compared to those for the manufacture of electronics, and so forth. Therefore, the panel predicted that Japan would continue to have both market share and profits, which would fund R&D.

The panel judged the United States' investment in advanced computing R&D unimpressive. Because future government funding was uncertain, industry has been left with an increasing responsibility for funding computer-related R&D. IBM has taken a leadership position in forming cooperative ventures, although some collaborative ventures had not lived up to expectations. Therefore Japan's position in advanced computing hardware could become dominant unless new initiatives are undertaken.

ADVANCED COMPUTING IN JAPAN

December 1987

Marvin Denicoff, Thinking Machines Corporation (Panel Chair)

Joseph A. Goguen, SRI International

Carl Hewitt, Massachusetts Institute of Technology

David Mizell, University of Southern California, Information Sciences Institute

Stanley Rosenschein, SRI International

Edmond Schonberg, New York University

Jay M. Tenenbaum, Schlumberger Palo Alto Research

SUMMARY

This panel's objective was to examine and evaluate progress in Japanese advanced computing, encompassing but not limited to work on the Institute for New Generation Computing Technology (ICOT) Fifth Generation (5G) Project since 1982. Beyond providing an overview of the Japanese effort, the panel focused on the particular research areas fundamental to realizing the announced goal of the 5G program -- to "provid[e] for the conditions and information demands of the society of the 1990s."

The panelists concluded that the Japanese effort to date had produced no fundamental advances. It had, however, scored points in such important areas as (1) establishing Japan as a full partner in the international community of computer scientists and scholars; (2) demonstrating awareness, beyond that of other countries and most particularly that of the United States, of the appropriate literature and most recent progress in the entire field of computer science; and (3) creating artificial intelligence (AI) and software products and tools of high quality, along with an organizational R&D planning mechanism to ensure the timely and efficient transfer of research results into products. The panel also found some research gaps: in proving the correctness of computer programs, in transformational programming, and in several areas of artificial intelligence.

COMPUTER SCIENCE IN JAPAN

December 1984

David H. Brandin, SRI International (Panel Chair)

Jon L. Bentley, Carnegie Mellon University

Thomas F. Gannon, Digital Equipment Corporation

Michael A. Harrison, University of California at Berkeley

John P. Riganati, National Bureau of Standards

Frederic N. Ris, IBM Thomas J. Watson Research Center

Norman K. Sondheimer, University of Southern California

SUMMARY

The JTEC panel on computer science examined a narrow domain of computer science in Japan and drew comparisons with similar technologies in the United States. The scope of the study included: software (software engineering, operating systems, applications packages, languages, databases); artificial intelligence and man-machine interface (Japanese character processing, speech recognition, machine translation, expert systems and ICOT, tools for artificial intelligence R&D, natural language understanding); architecture (parallel processors, supercomputers, workstations, clones, etc.); and communications (local area/value-added networks, hardware, protocols/software, FAX/office automation).

General Conclusions

The panel's overall conclusions were that Japan was far behind the U.S. in basic research and slipping further; behind the U.S. in advanced development and holding that position; and comparable with the U.S. and beginning to pull ahead in product engineering. The panel noted that the United States could be expected to dominate basic computer science research over the next decade because of its present base and momentum. The Japanese were aware of their deficiencies in this area and, although their system was not then well structured to perform basic research, they had begun to address the issue. Another factor was that the market share of U.S. companies would affect the profits available for maintaining the U.S. research base. The U.S. should not expect to maintain its edge in basic research indefinitely.

OPTO- AND MICROELECTRONICS IN JAPAN

May 1985

Harry H. Wieder, University of California, San Diego (Panel Cochair)

William E. Spicer, Stanford University (Panel Cochair)

Robert S. Bauer, Xerox Corporation

Federico Capasso, Bell Laboratories

Douglas M. Collins, Hewlett-Packard High-Speed Devices Laboratory

Karl Hess, University of Illinois at Urbana-Champaign

Harry Kroger, Microelectronics and Computer Technology Corporation

Won-Tien Tsang, AT&T Bell Laboratories

Jerry M. Woodall, IBM Thomas J. Watson Research Center

SUMMARY

New technologies in the field of solid state electronics and optoelectronics are concerned with the development of digital and analog processing systems based on electronic and photoelectronic devices and integrated circuits (ICs) that operate at much higher rates and with lower dissipation than do those of silicon-based technology. The panel considered the Japanese to be aggressive in acquiring, improving, and implementing these technologies, the conceptual aspects of which were developed in the United States. The panel felt that the Japanese would continue to use their adaptive ingenuity to produce market-oriented products and that their original creative contributions to this field would increase steadily in the future.

The panel concluded that the United States was maintaining equity or leadership in the synthesis of compound semiconductors. They found that the Japanese had committed substantial amounts of money for research on quantum wells and superlattice structures. In assessing Japanese and U.S. research and development of semiconductor near-infrared heterojunction lasers, light-emitting diodes, and integrated optics, the panel found that the U.S. was still leading in the system development area, but the Japanese had surpassed the U.S. in component

development. The panel considered the quality of Japanese research to be high, the R&D efficient, and the technology transfer from laboratory to pilot plant production effective, particularly in process-intensive areas.

The panel arrived at similar conclusions after examining Japanese research on heterojunction avalanche photodetectors and optoelectronic integrated circuits with a spectral range compatible with the radiation emitters. Optoelectronic research in Japan had a broad scope and was long-term in character, and was marked by cooperation between industrial laboratories and between industry and government. A comparative assessment of Japanese and U.S. research concerning ohmic contacts and Schottky barriers led the panel to conclude that both countries had a similar perception of the nature of metallurgical problems and the approach to potential solutions. The scale of Japanese plans and programs on solid state lasers in the near-infrared and visible portions of the spectrum was indicated by the fact that integrated optoelectronics was a more than $100 million research cooperative and was specifically targeted by MITI. Including optical devices, office equipment, and fiber optics systems, Japanese production was expected to rise from a base of $34 million in 1980 to $50 billion by the turn of the century.

The panel stated that the conceptual device aspects of insulated gate field-effect transistors were developed primarily in the United States. However, by the time of this study, work in Japan had reached a comparable level, both in university R&D and in industrial laboratories.

The panel noted that many Japanese are fluent in, or at least conversant with, technical and scientific aspects of the English language. U.S. scientists and engineers would do well to not only master the rudiments of the Japanese language, but also to reach a level of fluency that would permit them to attend and participate in technical and scientific meetings conducted in Japanese.

ADVANCED SENSORS IN JAPAN

January 1989

G. Laurie Miller, AT&T Bell Laboratories (Panel Chair)

Henry Guckel, University of Wisconsin at Madison

Eugene Haller, University of California at Berkeley

Takeo Kanade, Carnegie Mellon University

Wen Ko, Case Western Reserve University

Veljko Radeka, Brookhaven National Laboratory

SUMMARY

JTEC chose the topic of sensors because Japan is a preeminent manufacturing nation the economic strength of which depends primarily on the export of manufactured goods and because sensors play a critical role in the monitoring and control of manufacturing processes. However, because sensors are the means by which machines of any nature interact with and obtain information from their environment, the subject was both pervasive and diffuse.

The panel studied machine vision, sensors for electromagnetic radiation, factory automation and robotic sensors, micromechanical sensors, and gas/ion/biosensors.

Sensor Trends

The field of sensors is peripheral to, and dependent on, technologies developed primarily for other purposes. For example, the developing area of microstructures for sensor applications exploits silicon photolithographic and fabrication capabilities devised for microcircuit manufacture. The surge in optical sensor work rides on the extensive development of devices and fibers for fiber-optic communication, and the parallel rapid evolution of ever higher-resolution imaging cameras and other devices for such areas as high definition television and consumer optoelectronics.

The field of chemical/gas/biosensors has huge potential in health, food, and environmental monitoring areas. Such sensors depend largely on ensuring that the chemical or ionic species of interest are first selectively filtered by or attached to specialized materials. The sensing action takes place by a secondary step.

Similarly, the signal handling aspects of sensors are increasingly exploiting the capabilities of on-chip signal processing, with various highway and local area network schemes for information transfer. The issues of signal interpretation are increasingly important, particularly as the number and variety of quantities sensed become larger. This field makes contact with aspects of pattern recognition and the fringes of artificial intelligence while benefiting from having a genuine area of application and a test-bed on which to develop a fundamental understanding.

And finally, in the field of new materials, ceramics of all kinds (not least of all the $Y_1BA_2Cu_3O_7$ variety) are playing a leading role. To such possibilities must be added new semiconductor materials and structures, and ever-improving polymers and specialized materials permeable to specific ions for chemical sensors and biosensors.

Technical Conclusions

The types and performance of most commercially available sensors was comparable in the U.S. and Japan. Rapidly developing exceptions included Japanese high-resolution charge-coupled device (CCD) imagers for TV and machine vision.

The best U.S. research work and sensing devices were unexcelled, but this work was largely irrelevant to the productive side of the U.S. economy. There seemed to be a basic difference in orientation between the two countries. Much U.S. work was aimed at solving exceedingly hard problems in the hope that the solutions would spin off into productive use, whereas Japanese efforts tended to concentrate on solving ever more demanding problems as they arose in practice.

In addition to high-resolution CCDs, other sensor-related areas in which Japan was establishing a lead involved engineering materials such as high-technology ceramics and materials for biosensors. Some of this emphasis was reflected in the enhanced production control needed to manufacture fine ceramics and specialized materials such as those for piezoelectric actuators. One example was the low-cost ultrasonic motor, which was an exclusively Japanese development.

Industrial Conclusions

According to a survey conducted by the panel, the U.S. sensor industry did not see itself as being at risk. Although the industry might have been correct, there were individual islands of substantial concern. An example was the recent fall from world preeminence and subsequent dissolution of the entire RCA photodetection and photomultiplier operation; the whole area of photon detection had since been dominated by Hammamatsu.

Vertical integration was proving particularly advantageous to Japanese companies in sensor development. Thorough coverage of all aspects of sensor work was evident even with companies not expected to be specialists in certain sensor areas.

Contrary to much U.S. perception, Japanese company-to-company competition and rivalry were intense. Japanese companies viewed other Japanese companies as their primary threat, not U.S. technical competition. Also, the drive for lower cost seemed much stronger in Japan than in the U.S.

Organizational Conclusions

The panel found the overall planning and funding mechanisms for sensor work in Japan to be very complex, involving multiple interrelated committees and organizations. Much of the work itself tended to be long-term and very methodical. Individual companies' internal R&D, government organizations (e.g., MITI), large trade organizations, and quasi-private organizations (e.g., JRDC) all played a role.

Although industry-to-university cooperation had not been strong in the past, it was increasing as the Japanese Ministry of Education allowed more flexibility in university use of industrial funds and equipment. In the U.S., universities were traditionally viewed as the major source of new research findings, with industry playing a secondary role. However, in Japan much of the most advanced work was being done by industrial organizations. This situation now seemed to be changing, with increasing cooperation among university and industrial groups.

Overall Conclusion

Japanese sensor work was advancing steadily over a broad front in response to the demands of an increasingly sophisticated consumer and manufacturing market. Much Japanese high-technology development depended on very careful engineering of consumer products and their subsequent transition to higher-technology applications. The optical sensing and readout of consumer audio compact discs and their current re-engineering into magneto-optic storage peripherals for computers constituted an outstanding example. By contrast, much of the highest-technology U.S. sensor work was targeted on areas that provided little or no benefit to the productive side of the economy. U.S. sensor work had not attempted to emulate the Japanese model of continuous feedback and improvement.

COMPUTER-INTEGRATED MANUFACTURING AND COMPUTER-ASSISTED DESIGN FOR THE SEMICONDUCTOR INDUSTRY IN JAPAN

December 1988

William C. Holton, Semiconductor Research Corporation (Panel Chair)

Jean Dussault, AT&T Bell Laboratories

David A. Hodges, University of California at Berkeley

C.L. Liu, University of Illinois at Urbana-Champaign

James D. Plummer, Stanford University

Donald E. Thomas, Carnegie Mellon University

Bevan Wu, IBM Research Division

SUMMARY

Computer-integrated manufacturing (CIM) and computer-aided design (CAD) are two technical areas that have been key to the dramatic growth of the integrated circuit (IC) market. Today, IC technology has become the basis of all high-technology fields. Thus, if the United States wishes to maintain international competitiveness in high-technology markets, it must maintain its leadership in ICs and, consequently, in CIM and CAD as well. This panel examined the United States' competitive position in these technologies by studying the quality and direction of Japanese R&D in CIM and CAD compared to similar U.S. activities.

Computer-Integrated Manufacturing

Although research directly related to CIM is nearly nonexistent in Japan, several years ago the Japanese began to invest heavily in the pragmatic implementation of CIM systems in their large dynamic random access memory factories. To date, each of the major Japanese semiconductor manufacturers has separately invested about 100 person-years of effort in this technology. This investment has resulted in a highly sophisticated capability that has had a direct impact on the manufacturing competitiveness of these companies.

At the time of this study, these systems could be implemented in Japanese factories at a cost of 5 percent of the manufacturing equipment cost, exclusive of the plant cost, and could be maintained and upgraded with not more than 20 employees for a 30,000-wafer-per-month factory. The payback analysis was a 42 percent reduction in turnaround time, a 50 percent increase in unit output, an average increase in equipment uptime of 32 percent, and a 25 percent reduction in required direct labor hours. Japan had a five-year lead over the U.S. in the application of this technology. This accomplishment permitted the Japanese to begin applying CIM to application-specific integrated circuit factories.

Table 10 shows the panel's general assessment of CIM in Japan compared to the United States.

Table 10
CIM in Japan Compared to the United States
(See Key, p. xvii)

	R&D		Implementation	
Area	**Status**	**Trend**	**Status**	**Trend**
System architecture	-	>	++	=
Implementation of factory functions	0	=	++	=
Implementation of business functions	0	=	+	>
Role of modeling and simulation	0	>	0	>
Role of knowledge-based expert systems	0	>	0	=
Management of change	0	=	0	=

Computer-Aided Design

CAD tools are used in the design process to assist the IC design engineer in translating the initial electronic equipment specification to the specification for the photomasks used in IC manufacturing and to develop the procedures for testing the manufactured ICs. CAD is made possible through the development of a suite of software tools and suitable computers and terminals, all of which constitute the design engineer's interactive environment.

The development of CAD was pioneered in the United States at universities and large vertically-integrated corporations. At the time of the panel's report, all major Japanese IC manufacturers and vertically-integrated U.S. manufacturers had developed their own CAD tools internally, and did not share them. The panel judged from the relative complexity of IC products designed by Japanese manufacturers that CAD capability in Japan was comparable to that in the U.S., although the U.S. still held a lead in some areas. The CAD capability of non-vertically-integrated U.S. corporations was dependent on CAD system vendors, which existed exclusively in the United States and whose technology was dependent on U.S. universities. The Japanese also used tools purchased from U.S. vendors. Companies in the United States could not buy tools from Japan because independent CAD vendors did not exist in Japan and because Japanese universities were not heavily engaged in research related to CAD.

The panel's general assessment of CAD in Japan compared to the United States is shown in Table 11.

Table 11
CAD in Japan Compared to the United States
(See Key, p. xvii)

	Research		Development	
Area	**Status**	**Trend**	**Status**	**Trend**
Design and synthesis	-	=	-	=
Simulation	-	=	0	>
Physical design	-	=	0	=
Verification and test	0	=	+	>
Hardware accelerators	0	=	+	>
Test	+	>	+	>

TELECOMMUNICATIONS TECHNOLOGY IN JAPAN

May 1986

George L. Turin, University of California at Los Angeles (Panel Chair)

William H. Davidson, University of Southern California

Paul E. Green, Jr., IBM

James Mikulski, Motorola, Inc.

Albert E. Spencer, Jr., AT&T Bell Laboratories

Bruce A. Wooley, Stanford University

SUMMARY

This panel placed its evaluation within the context of the dramatic structural changes that were occurring in Japan's domestic telecommunications service industry -- privatization of NTT, Japan's publicly-owned monopoly in domestic telecommunications carriage; deregulation of telecommunications services to allow competitive entrants into the market; and liberalization of restrictions that had virtually barred foreign participation in the domestic equipment market.

At the lowest building-block level of the telecommunications equipment market -- semiconductor and optoelectronic components -- the panel found Japan's R&D efforts, ranging from basic research on materials and fabrication technology to product development, to be among the best in the world. At the next level -- the subsystems from which telecommunications networks are built -- the quality of Japanese R&D was mixed, the panel said. It found R&D to be best at the product development end of the spectrum and weaker at the basic research end. But research in such areas as radio propagation for mobile radio systems, digitization of radio systems, and lightwave transmission systems was excellent. At the level of complete networks, the panel did not consider Japan to be a substantial force internationally.

III. MATERIALS

ADVANCED COMPOSITES IN JAPAN

March 1991

R. Judd Diefendorf, Clemson University (Panel Chair)

William Hillig, General Electric Research and Development

Salvatore J. Grisaffe, NASA Lewis Research Center

R. Byron Pipes, University of Delaware

John H. Perepezko, University of Wisconsin

James E. Sheehan, MSNW Inc.

SUMMARY

The JTEC Panel on Advanced Composites surveyed the status and future directions of Japanese high-performance ceramic and carbon fibers and their composites in metal, intermetallic, ceramic, and carbon matrices.

Japan's ambitious space program includes development of a hypersonic civilian aircraft, to be completed by 2005. A major factor in the program is new materials, one of three areas selected by MITI for national development investment. The Japanese believe that technological superiority in space structures and launch systems could help them become dominant in the aerospace market.

Japanese industry and government are willing to forgo short-term gains to build for the future. The new MITI materials thrust initiated in 1989 (*High Performance Materials for Severe Environments*) was scheduled to continue for almost ten years, longer than would be possible in the U.S. The Japanese support parallel approaches to materials research and technology that often involve overlapping activities among several groups, sharing information at the precompetitive stage. By contrast, the U.S. seems to select one best approach initially, frequently finding later that other options are needed.

By attempting to find an immediate application for less-than-optimum materials, the Japanese gain the manufacturing experience to produce a lower-cost, more reliable

product. For this reason, they tend to place less emphasis on basic science and more on manufacturing and large-scale pilot plants. Compared with the U.S., there seems to be more learning by doing and fewer analytical studies.

Some previous MITI materials programs have led to new consumer markets and substantial returns on government investment. The Japanese formed technical teams within and across industries that remained intact for the long periods required to develop and exploit markets. The 1989 MITI initiative was different: although materials would be an enabling technology for a hypersonic transport vehicle, they might only be produced in small quantities. MITI also set very ambitious performance for its new program in 1989. The panel felt that these goals would be revised downward to achievable levels.

Because of a strong carbon and fiber industry, Japan is the leader in carbon fiber technology. Japan has initiated an oxidation-resistant carbon/carbon composite program. With its outstanding technical base in carbon technology, Japan should be able to match present technology in the U.S. and introduce lower-cost manufacturing methods. However, the panel did not see any innovative approaches to oxidation protection.

Ceramic and especially intermetallic matrix composites were not yet receiving much attention at the time of the panel's visit. There was a high level of monolithic ceramic R&D activity. High-temperature monolithic intermetallic research was just starting, but notable products in titanium aluminides had already appeared. Matrixless ceramic composites was one novel approach noted. Technologies for high-temperature composites fabrication existed, but large numbers of panels or parts had not been produced.

The Japanese have selected aerospace as an important future industry. Because materials are an enabling technology for a strong aerospace industry, Japan initiated an ambitious long-term program to develop high-temperature composites. Although the program was just starting, its progress should be closely monitored in the U.S.

Reinforcements

High-temperature/high-performance composites for aerospace applications depend on the availability of strong, lightweight fibers. Japan's commitment to several advanced aerospace efforts -- for example, Mach 4-6 hypersonic technology -- make its fiber accomplishments of particular interest. Japan has done well in developing a number of useful fibers, primarily through the polymer precursor approach. The Japanese are learning how to produce quality fibers in reasonable quantities and fabricate lower temperature composites with the fibers. They are developing insights into advanced composite fabrication and higher temperature composite durability, which would help them exploit improved fibers as they become available.

Ceramic Matrix Composites

Japanese researchers have focused on enhancing the toughness of the best already-available monolithic structural ceramics. Japan has been a prime supplier of continuous high-performance, high-temperature fibers that have been used in the development of ceramic composites in the U.S.. The Japanese themselves have focused on the use of SiC and Si_3N_4 whiskers and particulates.

The Japanese are also devoting significant effort to processing hybrid ceramic/metal composite systems. They are developing sophisticated techniques for making functionally gradient materials (FGMs) whose properties change gradually from ceramic to metal. FGMs are designed to overcome the severe problems of thermal expansion mismatch in joining metal to ceramic parts in high-temperature engines. A separate processing effort is directed at making the high-temperature, high-performance composite materials into shapes needed for such engines. This effort involves combining self-propagating high-temperature synthesis with hot isostatic pressing to produce high-quality material in the desired complex shapes.

Metal and Intermetallic Matrix Composites

Japan entered the field of metal matrix composites about a decade later than the U.S. did. However, the Japanese have more than made up for lost time. At the time of the panel's visit, the Japanese had not developed widespread commercial applications for metal matrix composites; rather, the focus of activity was development of lower-cost production methods. The Japanese R&D programs also emphasize self-sufficiency in components. Some early successes have been achieved with intermetallic alloys that perform well in high-temperature turbines.

Carbon-Carbon Composites

The technology for fabrication of fiber-carbon matrix (C-C) composites has been funded by the U.S. government for almost twenty years. A mature domestic industry is manufacturing large, complex C-C shapes. In contrast, Japan has only recently begun to emphasize C-C components manufacturing. Although several Japanese companies possess the facilities and basic understanding to produce C-C components, the lack of applications and design experience has put Japan at a disadvantage.

C-C manufacturing innovation in Japan is driven in part by a concern with production costs and associated efforts to identify commercial nonaerospace applications for C-C composites. Japanese efforts to develop new low-cost fabrication methods have no parallel in the U.S. Clearly, even if new and significant industrial uses are not realized, the Japanese aerospace industry would very likely benefit from such improvements in C-C manufacturing methods.

HIGH-TEMPERATURE SUPERCONDUCTIVITY IN JAPAN

November 1989

Mildred S. Dresselhaus, Massachusetts Institute of Technology (Panel Chair)

Robert C. Dynes, AT&T Bell Laboratories

William J. Gallagher, IBM

Paul M. Horn, IBM

John K. Hulm, Westinghouse Corporation (retired)

M. Brian Maple, University of California, San Diego

Rod K. Quinn, Los Alamos National Laboratory

Richard W. Ralston, Los Alamos National Laboratory

SUMMARY

To study and assess the state of the art of Japanese R&D in superconductivity, the panel first prepared a preliminary assessment of the state of the art in the United States. In ten days, the panel visited three university, eleven industrial, and seven government laboratories. Panel members interacted with Japanese leaders in superconductivity R&D and with many younger, active researchers. The panel then prepared appraisals of Japan's basic superconductivity program, materials research, large-scale applications, materials processing, and electronics applications, including thin-film R&D.

The panel found that Japan has a deep, long-term commitment to superconductivity R&D in industry, academia, and national laboratories. This commitment could be seen in several factors -- such as the number of people involved in superconductivity R&D, which was about the same as in the United States, although the Japanese population was less than half that of the United States at the time of the panel's visit in 1989. Several five- to ten-year superconductivity projects were in place, sponsored by MITI, the Science and Technology Agency (STA), the Ministry of Education (Monbusho), and Japanese Railway.

Because of its perceived scientific and technological importance, superconductivity had been selected as a flagship to show the world that the Japanese could be

successful in fundamental scientific research. Although the Japanese had been extremely successful in advanced technology and commercialization, they were criticized for their lesser contributions to basic research. To answer this challenge, the Japanese were taking bold steps to enhance their basic research effort in superconductivity. This included increasing support to leading academic groups, establishing MITI's International Superconductivity Technology Center (ISTEC), strengthening their infrastructure for basic research, and promoting personnel exchanges with foreign countries. The panel judged Japan and the U.S. to be comparable in basic experimental studies and materials research, but the Japanese were improving rapidly and competing strongly.

The Japanese identified superior materials as the key to success in high temperature (high-T_c) superconductivity research and technology. They were translating this philosophy into a sustained, systematic approach to materials synthesis and processing, including new materials research. Most of the outstanding achievements of the Japanese in the field of superconductivity stemmed from this systematic approach, which was reinforced by a top-down management structure and an appreciation of the people who did materials synthesis, processing, and scale-up. The Japanese were leading the United States in their ability to mount sustained, systematic materials R&D programs, and they had a better trained work force to implement such programs. However, although Japan's top-down management system may be excellent for reinforcing sustained, systematic research, it could be less conducive to creativity.

In basic science, interaction between groups in different Japanese organizations in industry, university, and government laboratories was not as strong as in the United States, although teamwork within an organization tended to be stronger. With government leadership, the Japanese were taking steps to break down the interorganizational barriers by funding large interuniversity programs, establishing R&D consortia such as ISTEC, and encouraging strong project-related interorganizational collaborations (which, however, tended to be in applied areas). Examples of interorganizational efforts in applied areas were the Josephson Scientific Computing System project and the Multi-Core Project in Superconductivity. The latter was aimed at developing high-T_c superconductors to the point of commercialization. The government had successfully encouraged technology transfer from government laboratories to industry in the areas of large-scale superconducting magnet projects and low-T_c Josephson junction electronics.

Japanese universities' facilities and infrastructure for superconductivity research had steadily improved, so that the best Japanese universities were equipped nearly as well as their U.S. counterparts. The equipment and facilities for superconductivity R&D in Japanese industry and national laboratories were equal or superior to those in the United States and were steadily improving. Research opportunities in Japan had begun to attract foreign talent, despite the large social and language barriers.

The Japanese had developed a strong industrial base for the large-scale application of low-T_c superconductivity. While U.S. consortia were being organized to enhance technology transfer, the Japanese already had a ten-year history of successful technology transfer in large-scale superconductivity applications. R&D personnel at the national laboratories had worked collaboratively through the R&D cycle with electrical industries and with wire and cable companies. These collaborations had produced an array of large magnet systems for magnetic fusion, high-energy physics, magnetic levitation, power generation, and magnetic resonance imaging applications. Japanese capabilities in superconducting wire for the next generation of magnets (above 15 tesla) significantly exceeded U.S. capabilities, and the gap was widening.

Low-T_c Josephson digital capabilities at four Japanese laboratories far exceeded those at any laboratory in the United States. One overwhelming achievement of the MITI superconducting electronics project was low-T_c digital chip technology, which provided a model of technology development and transfer through a national laboratory-industry collaboration. By 1989, Japan dominated digital Josephson technology, and Japanese companies were well positioned for possible future commercialization.

However, because the United States had greater analog superconducting device expertise, U.S. efforts in these devices were well advanced over those in Japan. Because early high-T_c electronics applications would very likely be in analog devices, the United States was considered to be well positioned to lead in these areas. U.S. leadership would be threatened, however, if superior low-T_c technology remained the norm in Japan, and if the analog device expertise in Japan grew in conjunction with expanded superconducting thin-film and electronics developments. The Japanese were maintaining strong low-T_c electronics programs as a critical component of their superconducting technology development effort.

Japan and the United States were both strong in superconductivity R&D. Thus they would have many opportunities to work together and learn from each other. Because the Japanese placed greater emphasis on sustained, systematic materials research, they were offering the United States strong competition in research and were developing the potential to pull ahead in commercial applications.

ADVANCED MATERIALS IN JAPAN

May 1986

James Economy, IBM Research Division (Panel Chair)

Michael Jaffe, Celanese Research Company

William J. Koros, University of Texas at Austin

Raphael M. Ottenbrite, Virginia Commonwealth University

Elsa Reichmanis, AT&T Bell Laboratories

John R. Schaefgen, DuPont Textile Fibers Pioneering Research Laboratory (retired)

SUMMARY

Between 1950 and 1970, the major chemical companies of Japan licensed or set up joint ventures to manufacture practically all of the commercially available polymers. After 1970 there was an increasing flow of upgraded technology from Japan to the United States. MITI and leaders from the chemical industry had spearheaded a national strategy designed to make Japan the world leader in advanced materials by the 1990s. This strategy committed resources to a given area for a ten-year period.

The JTEC panel found that Japan's chemical industry had a number of advantages over its U.S. counterpart in competing for the future market in advanced materials. Automation in the Japanese chemical industry had increased the revenue per employee to $500,000, compared with $125,000 in the typical U.S. company. A pattern of establishing affiliates and subsidiaries to exploit new opportunities was firmly entrenched in the Japanese system, while most major U.S. companies were still trying to handle new ventures within their existing structure. Over the past five years, Japanese chemical companies had greatly increased their R&D (with modest government support), more than matching the 50 percent increase in R&D by U.S. companies over the past decade. And finally, the panel found that Japanese scientists excelled in addressing near-term, well-defined technical problems, although they were not as well trained to address longer-range problems requiring intuitive skills.

IV. Manufacturing and Construction

MATERIAL HANDLING TECHNOLOGIES IN JAPAN

December 1992

Edward H. Frazelle, Georgia Institute of Technology (Panel Cochair)

Richard E. Ward, Material Handling Industry (Panel Cochair)

James M. Apple, Jr., Coopers & Lybrand

Thomas C. Day, Hanover Direct

Glenn J. Petrina, Defense Logistics Agency

Alvin R. Voss, IBM

Howard A. Zollinger, Zollinger Associates

SUMMARY

Material handling plays a vital role in all sectors of business and commerce, but nowhere is it as important to an efficient operation as it is in manufacturing, warehousing and distribution. Those who study this field and understand how material handling methods, equipment and systems can be used to increase productivity look on the material handling process and the technologies available as strategic competitive factors. Cost reduction (capital and operating), increased throughput, improved response times, work place safety, and total quality are measures of performance that have strategic implications for a business. These factors are all directly affected by how well an organization performs its material handling functions.

These factors alone are enough to cause business leaders to want to study this field and to research best practices and available technology worldwide. The strategic advantages that many say Japan has in a wide variety of industries (e.g., automobiles and consumer electronics) present a particular impetus for studying developments in and applications of material handling in Japan. Japan's competitive position in high technology manufacturing helped motivate the National Science Foundation and the Department of Defense to commission an expert panel to conduct a study of

material handling in Japan that would include visits to Japanese suppliers and users of material handling technologies.

This report synthesizes the findings from approximately sixty site visits, attendance at major Japanese trade exhibitions, a review of current literature, and discussions with numerous Japanese experts in the field. Although much of the research was conducted during the first five months of 1992, visits dating back to 1990 provided additional valuable information. A summary of the conclusions drawn from this study follows:

1. *Prior to 1960 Japan trailed the United States in industrial productivity and in the application of modern production methods, especially in the use of state-of-the-art material handling technology. All that has changed.*

In the late 1950s the Japanese Productivity Center sent a team to the U.S. to study what was being done in material handling and to recommend measures for implementation in Japan. The result was the licensing of U.S. material handling technology for production and use in Japan. Today, we see spin-offs and derivations of that early technology, which has improved vastly in several areas. Japan is not only using its own material handling technology and equipment domestically, but Japanese suppliers are selling them on a worldwide basis, including in the United States. Japan is now a leader in several equipment/technology categories.

2. *Productivity improvement--and the strategic advantages that accompany such improvement--have provided the rationale for Japan's quest for the best production methods and technologies over the last thirty years. However, that rationale today is being amplified manyfold by changing demographic, social, and business conditions in Japan. The result has been an acceleration in the application of automated material handling systems that dwarfs what we see occurring in the United States.*

The evidence is fairly clear that factors such as declining population, aging work force, changes in work preferences, and the ever-present congestion and lack of space are fueling the use of automation. The corollary in this case is that demand (application and use of automated material handling technologies) fuels supply, which translates into a rationale for ongoing research and product development. In many cases, economies of scale in the production of material handling equipment can also be associated with high demand levels.

3. *Automated material handling equipment and systems in Japan are not deployed exclusively in large, complex integrated systems. The result is many examples of simple, stand-alone installations.*

This factor partially explains the extremely high Japanese material handling equipment installation statistics in comparison to those in the United States. In the United States such installations are often called "islands of automation," and are generally viewed as less than desirable. In Japan, however, stand-alone installations mean greater control and cost savings. Two business factors have contributed to greater use of simple, stand-alone installations in Japan. One is the general Japanese attitude that simple is best. The other is the availability of Japanese users willing to make use of such systems without demanding often costly modifications and "bells and whistles." A benefit of this phenomenon is that it has allowed Japanese suppliers to concentrate on research and development that focuses more on issues such as product reliability and maintainability.

4. *The Japanese government has taken an active policy role in stimulating the application of automated material handling systems.*

The 1958 study team is perhaps the earliest, albeit an indirect, example of Japan's active government policy. A more direct example has been the Japanese government's policy of making funds available at attractive lending rates for capital projects that address demographic changes in the Japanese work force. The strategic significance of investments, coupled with a long-term view of their benefits (versus short-term payback), has long been recognized as something that differentiates Japanese attitudes about capital investments in business infrastructure from attitudes in the United States. The added motivation of having access to capital at attractive rates for the specific purposes stated above only compounds the advantages enjoyed by Japanese manufacturers.

5. *Research and development in the field of material handling, though very active, is apparently performed exclusively within the confines of private industry.*

This is no different from what takes place in the United States or elsewhere. In the United States, however, there is evidence of greater academic interest in the field of material handling. This has led to the direct incorporation of material handling into U.S. college curricula, and to more independent research associated with the operational design and control of material handling systems. This is not to be confused with electro-mechanical design or testing. There is little to no work of this type underway at U.S. or Japanese universities. Nevertheless, there is greater evidence of industry sponsorship of college and university material handling education and research in the U.S. than in Japan. There is somewhat of a dichotomy here because the rate of investment in material handling automation in Japan far exceeds that in the United States, regardless of what is done in or by universities.

6. *Industrial productivity in Japan still lags behind the productivity of U.S. industry, but the two have been converging rapidly.*

Japan's material handling practices have contributed significantly to its gains in productivity. The gains have been made possible by the enlightened attitude of Japanese business managers, the types of products and systems that Japan's material handling industry delivers to the market place, and the way that Japanese suppliers and users work together to accomplish an objective.

7. *An assessment of whether Japan is ahead or behind in its material handling technology depends on the technology being examined.*

A broad spectrum of equipment categories is analyzed in Figure 21.

CATEGORY	DEVELOPMENT status	DEVELOPMENT trend	APPLICATION status	APPLICATION trend
AS/RS				
unit load	o	↗	+	↗
mini load	+	↗	+	↗
AGV				
unit	o	→	+	↗
small	o	→	+	↗
AEM				
unit	o	↗	+	↗
small	+	↗	+	↗
CONVEYOR				
transport	o	↗	o	→
sortation	−	↘	−	→
SORTING TRANSFER VEHICLE	+	↗	+	↗
DEPALLETIZING (for case pick)			o	→
Carousel	−	↘	−	↘
Rotary Rack	+	↗	o	→
Intel. Pick Cart	+	↗	+	↗
Lt. Aided Picking	+	↗	+	↗
Clean Rm. Syst's	+	↗	−	→
CONTROLS:				
Radio Freq.				
machine cntrl			−	→
operator cntrl			+	↗
Dock Mgt.	+	↗	+	↗
Warehouse Mgt. Sys.			−	→
Auto ID			−	↘
EDI			−	↘
Implement. Time & Smooth Startup	+	→	+	→

+ = Japan ahead ↗ = Japan gaining ground

Figure 21. Comparison of U.S. and Japan in Material Handling Technologies

CONSTRUCTION TECHNOLOGIES IN JAPAN

June 1991

Richard L. Tucker, Construction Industry Institute (Panel Chair)

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SUMMARY

To evaluate the innovation and effectiveness of R&D in Japanese construction technologies, the JTEC panelists focused on processes, materials, and systems. They examined R&D; materials; field operations; and automated equipment, building systems, and structural systems. They also examined management systems, safety, environmental technologies, and public/private interactions.

The Japanese Ministry of Construction (MOC) assists industry; its efforts are complemented by MITI, the Building Research Institute (BRI) and the Public Works Research Institute (PWRI). MITI's construction focus is on housing-related matters. The role of the MOC is to establish criteria for qualifying contractors to bid public works projects, promote R&D through the BRI and PWRI, and maintain the national building code. The U.S. has no such common code; many codes exist throughout the nation.

In Japan, a private contract is usually negotiated and a government contract awarded to the low bidder from a technologically prequalified group. Design-build contracting is common in private work, but design-then-build dominates public-sector projects. Japanese construction companies are led by engineers and architects who are familiar with the specific technology used on their projects. Like their U.S. counterparts, they are concerned about productivity and safety. To attack these problems, the large Japanese contractors conduct substantial R&D.

Research and Development

Of Japan's annual construction volume, 0.51 percent is spent on construction R&D, compared with under 0.1 percent in the U.S. for comparable sectors. As a matter of national policy, the Japanese see continued and increased R&D investments as important to upgrading housing, renewing and expanding the public infrastructure, and keeping their industrial capital base efficient and up to date. Industry, government, and universities generally work independently, yet there is cooperation in setting goals and working on certain priority areas.

Japanese construction companies have well-established in-house R&D programs, generously funded mainly from their own internal sources; the programs have well-equipped laboratories on a level almost totally absent in U.S. construction companies. Partly through application of their research findings, Japanese construction companies have moved ahead of their U.S. counterparts in many areas, including soft-ground tunneling, design and construction of intelligent buildings, deep foundation construction, construction robotics, and long-span bridge construction. They are likely to expand their lead rapidly in the future.

Government laboratories in both countries have good and approximately equal capabilities for construction R&D. The U.S. appears to have an advantage only in universities. In construction, Japanese universities seem isolated from industry and government R&D; they have few if any counterparts to NSF-funded engineering research centers and industry-supported centers at leading universities in the U.S.

Materials

Japan's government, manufacturing industry, and engineering-construction industry laboratories have given extensive, sustained, collaborative attention to the improvement of construction materials. R&D elsewhere in the world is monitored carefully and useful results licensed in Japan. Government research activities are more extensive than those in U.S. government laboratories. The Japanese manufacturing industry has increased R&D, but U.S. building materials manufacturers have been abandoning product development research to cut expenditures. Japanese engineering-construction firms have large-scale construction materials research efforts that are generally unmatched by U.S. counterpart companies. University professors and researchers collaborate in these efforts, but on a smaller scale than their U.S. counterparts.

Thus Japan matches or leads the U.S. in implementation of state-of-the-art construction materials technology and has growing leadership in research. Strong research and implementation activities have given the Japanese steel industry clear leadership in weldable and fire-resistant, high-strength structural steels. A major cooperative government, industry, and university program for high-performance concrete research is likely to give Japan leadership in this internationally significant area of construction technology.

Automated Equipment

Japanese companies have also invested heavily in developing automated equipment, although they have produced very few practical pieces. Much of their motivation to automate seems to stem from their desire to improve the image of the construction industry among workers, make construction safer, and help sell both existing customers and new prospects. Despite their push to automate construction equipment Japanese companies do not use computers for schedule or cost control as widely as U.S. companies do, relying instead on manual methods. However, Japanese companies are actively exploring ways to transfer information from computer-assisted design models to field equipment, and then manipulate that data from the surrounding environment using artificial intelligence.

Infrastructure

Improving Japan's infrastructure has depended on efficient development and use of space. The Japanese have sought new space by building up, building out, and building down. They attack the construction of office and apartment buildings from a new perspective: the building is a system and needs systems solutions. The concept of the intelligent building is key to this strategy. One of the MOC's key objectives for the 1990s is to achieve "good-quality housing and infrastructure that suit the needs of the nation." The boom in office building and home construction markets offers an excellent opportunity to apply high-technology concepts to building construction to improve the working and living environment.

The quality of buildings and support systems in Japan equal that of new buildings constructed in the U.S. Most of the systems are adaptations of existing technology, which may lead to a fusion of technology. Emphasis on automation, robotics, and new structural and construction systems to support super-high-rise buildings could lead to new breakthrough technologies in building systems by 2000. A wide range of structural systems are being systematically developed that focus on factory automation and use of robots and intelligent tools. Extensive use is being made of CAD/CAM systems for design, manufacture, and construction of structural systems. Although the U.S. is ahead in R&D efforts in these areas, implementation is at least equal, or even ahead, in Japan.

Structural Systems

Development and availability of thermomechanical process control (TMPC) steels in Japan place the Japanese well ahead of the U.S. in applying these special steels to structural systems. The Japanese experience indicates that these materials make steel structural systems more competitive for building and bridge applications. Concrete structural systems in Japan seem on a par with those in the U.S. for precast structural elements. In high-strength concrete for structures and high-rise construction, Japan appears to be lagging behind the U.S. The panel found that R&D efforts and trial implementation of active control damping systems for earthquake and wind resistance far exceed U.S. efforts. Passive control damping systems, such as base-isolated structures and special dampers, are being actively studied, and trial implementations are under way.

Conclusions

The Japanese have one of the most advanced construction industries in the world. Japan has long acknowledged the U.S. contribution to its technological and managerial practices. The Japanese have blended these practices into their culture, resulting in a robust construction industry that contributes significantly to the welfare of Japanese society. The U.S. construction industry could use some of the lessons learned by Japanese companies.

MECHATRONICS IN JAPAN

March 1985

James L. Nevins, Charles Stark Draper Laboratory (Panel Chair)

James S. Albus, National Bureau of Standards

Thomas O. Binford, Stanford University

J. Michael Brady, Massachusetts Institute of Technology

Michael Kutcher, consultant to IBM's Corporate Manufacturing Staff

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G. Laurie Miller, AT&T Bell Laboratories

Lothar Rossol, GMF Robotics

Karl B. Schultz, Cincinnati-Milacron

SUMMARY

The Japanese created the term "mechatronics" to describe the union of mechanical and electronic engineering needed to produce the next generation of machines, robots, and smart mechanisms for manufacturing, large-scale construction, and work in hazardous environments. This study evaluates Japanese R&D in mechatronics.

To analyze mechatronics, the panel divided the field into nine areas: flexible manufacturing systems, vision systems, nonvision systems, assembly/inspection systems, intelligent mechanisms, software, standards, manipulators, and precision mechanisms. The assessment summary showed Japanese basic research to be equal to that of the U.S. in all areas except vision and software. Furthermore, Japanese research was staying even with that of the U.S. In basic research, the Japanese were behind and falling further behind only in artificial intelligence (AI) software techniques. However, AI is not the only path to future intelligent systems, and Japan appeared to be taking a broad approach. In advanced development and product implementation, the Japanese were equal to or ahead of the U.S., and the rate of change was definitely in favor of Japan.

V. Aeronautics and Space Technology

SPACE ROBOTICS IN JAPAN

January 1991

William "Red" Whittaker, Carnegie Mellon University (Panel Chair)

James W. Lowrie, Martin Marietta Astronautics Group

Harry McCain, NASA Goddard Space Flight Center

Antal Bejczy, Jet Propulsion Laboratory

Tom Sheridan, Massachusetts Institute of Technology

Takeo Kanade, Carnegie Mellon University

Peter Allen, Columbia University

SUMMARY

Infrastructure and Program

Japan has been one of the most successful countries in the world in the realm of terrestrial robot applications. The panel found that Japan has in place a broad base of robotics R&D, ranging from components to working systems for manufacturing, construction, and human service industries. From this base, Japan looks to the use of robotics in space applications, and has funded work in space robotics since the mid-1980s. The Japanese are focusing on a clear image of what they hope to achieve through three objectives for the 1990s: developing long-reach manipulation for tending experiments on Space Station Freedom, capturing satellites using a free-flying manipulator, and surveying part of the moon with a mobile robot. This focus and a sound robotics infrastructure is enabling the young Japanese space program to develop relevant systems for extraterrestrial robotics applications.

Space robotics in Japan has involved government agencies, national research laboratories, universities, and companies. The government agencies responsible for space activities are the National Space Development Agency and the Institute of Space and Aeronautical Science, and, to a lesser extent, MITI.

Japanese industry recognizes the future potential of space, and the larger Japanese mechatronics companies engage in space robotics research. The panel found most industry research to be strongly applications-oriented. Government contracts have been let to companies with aerospace and industrial robotics experience; multiple contractors may take part in a major project. In the U.S., by contrast, one corporation usually acts as the prime integrating contractor. Japanese universities are also involved in space robotics research. Universities provide a stream of basic research contributions, but have played only minor roles in large robotics projects.

Funding for Japanese space robotics research and projects has come from the government, with cost sharing by corporations. Japanese procurement practices appear to have engendered cooperation among Japanese corporations, and companies have rotated contracts. Government contracts tend to be smaller and to make up a smaller proportion of a company's business in Japan than in the U.S. Less funding is apparently available in Japan than in the U.S., but major Japanese space robotics programs and a diversity of smaller projects are supported.

Japanese Experimental Module

The Japanese Experimental Module (JEM) is Japan's contribution to the international Space Station Freedom project. JEM is a space laboratory for experiments in areas such as biology and crystal growth. When deployed, JEM will have a pressurized module for researchers, an exposed facility for experiments, and a remote manipulator system (RMS) to service experiments and maintain the exposed facility. JEM's exposed facility portion is designed to be robot-friendly, eliminating the need for astronauts to perform routine maintenance and repair functions. The JEM/RMS has a large arm and small fine arm (SFA). The large arm is designed to conduct overall assembly tasks and to transport the SFA; the SFA provides dexterity. JEM's pressurized module includes an interior workstation for teleoperating the JEM manipulators using a single joystick.

JEM's large arm is mounted on the pressurized module just above the airlock and had 7 degrees of freedom (DOF). The manipulator is 9.7 m long and has a mass of 370 kg. It will maneuver a payload massing up to 7000 kg. Two cameras mounted on the arm permit the operator at the workstation to view large arm actions. A standard grappling mechanism is mounted on the end of the large arm to dock with tools, payloads, or the SFA.

The SFA relies on the large arm for transport, positioning, and stabilization. The SFA includes an interface with the large arm, an electronics module, camera assembly, manipulator, and end effector. This arm is 1.6 m long, has 6 DOF, and features a 3-DOF wrist. The SFA can move up to 10 cm/sec with a payload of up to 300 kg. A stereo camera mounted at the base of the manipulator displays images on a video monitor at the workstation.

In addition to the RMS, the Japanese have conceived the active compliance effector (ACE), which is designed to be mounted on the end of the JEM/RMS arm. ACE provides small motions that could be useful in compensating for inaccuracies of the large arm. ACE was particularly interesting to the panel because the U.S. was planning nothing like it for its long-reach space manipulation.

Orbital Operations

Japan has identified orbiting space structures as a means to conduct space activities in the future. In addition to the Space Station Freedom, the Japanese envision their own robotic space laboratory, the Cosmo-Lab, and one corporation hopes one day to operate an orbiting space hotel. To realize these scenarios, the Japanese foresee free-flying robots that grab, dock, and manipulate while in orbit. Fixed-base systems, such as those appended to shuttles or stations, have many limitations.

The Japanese are developing a free-flying manipulator with satellite capture capabilities. Named the Autonomous Satellite Retrieval EXperiment (ASREX), it is a scientifically motivated, special-purpose experimental robot for retrieving satellites. A key technology required for the ASREX is coupled control of the free-flying vehicle and manipulator. Movement of the manipulator will cause a reactive movement of the satellite, which must be compensated for by position and attitude control. The Japanese plan to accomplish satellite capture autonomously using feedback from laser radar, which is being developed specifically for this project. In addition to the ASREX, the Japanese are planning the ETS-7, an ASREX-like device that would be controlled by a combination of autonomy and teleoperation and would be capable of rendezvous and docking operations.

Japan's Space Flyer Unit (SFU) is a reusable satellite bus with onboard infrastructure, such as power, telemetry, and control, which could host free-floating experiments. Scheduled to fly in the early 1990s, it was justified independent of its relevance to space robotics, though it would enable scientific robotic experiments.

Japanese assembly and service robot concepts were still in the early planning stages at the time of the panel's visit. The Orbital Service Vehicle (OSV) is envisioned as a free-flying extra-vehicular activity (EVA) robot for inspecting, assessing, and repairing satellites or space structures. It will include thrusters, a manipulator, visual sensors, laser radar, a high-gain antenna, and a docking mechanism. *Hope* is envisioned as an unmanned shuttle-type vehicle. Its long-reach manipulator will transfer cargo, capture satellites, and aid in space assembly. As of 1990, the first launch was planned for the mid-1990s.

Surface Exploration and Construction

The Japanese are envisioning missions to the moon and to Mars, and speculate on the use of robots for surface exploration. Extreme conditions on other planets, including heat and cold, radiation, and rough terrain, require robots that are mobile; have competent motion in hard or soft terrain; remain upright or are self-righting; and that are physically self-contained, durable, and autonomous. In May 1990, the Japanese announced a three-part lunar survey mission projected for launch in 2000. The unmanned Lunar Mobile Explorer (LME) is planned to investigate soil characteristics, collect samples, and confirm the presence or absence of water under the moon's permanent shadow.

The Japanese are also conducting research and development in mobile robots for nonspace applications. They have developed several wheeled, tracked, and hybrid mobile robots. They have also conducted research on legged robots that were candidates for space applications. Although the Japanese have had no experience in developing and testing mobile robots on planetary surfaces, they have a wealth of experience in terrestrial analogs, particularly in nuclear and construction applications. This will be a clear advantage for future surface operations.

Supporting Technologies

The Japanese are performing basic research for future generations of robots. The panel encountered a spectrum of supporting technology, including task control, motion control, master-slave systems, novel mechanisms, actuators and devices, and special-purpose robot integrations. Task control technologies were advancing Japanese manipulation from teleoperation toward autonomy. The panel observed outstanding Japanese motion control technologies: position and force control, hybrid control, use of digital signal processors to successfully increase the response and stability of control systems, and miniaturized actuators and components.

One notable system uses a series of head-mounted video displays to drive a slave video camera. This system includes a master-manipulator, slave-manipulator, and real-time graphic simulator. Human movements, including head and eyeball movements, are measured in real time. The movements of the robot sensors are controlled to follow the human operator, and images taken by the robot sensors are displayed to the human operator's eyes. Other notable Japanese master-slave systems include a 6-DOF bilateral teleoperator with a kinematically dissimilar master and slave, a master-slave manipulation system with visual and force feedback, and teleoperators enabling dynamic manipulation.

Japanese robotics researchers have developed a number of novel mechanisms, actuators, and devices, including manipulators, serpentine mechanisms, and high-performance miniature actuators and controllers. One interesting flexible finger system is controlled by pneumatic servos. Each finger is a hollow rubber cylinder divided into three chambers that are pressurized independently. The fingers are moved by varying the pressure in the chambers. Each finger is capable of fine, controlled movement, e.g., threading a bolt into a plate.

Serpentine mechanisms have a great deal of potential for space applications because gravity loads do not apply. Such systems, morphologically and functionally analogous to snakes, tentacles, or elephant trunks, are characterized by long reach, narrow profile, and the ability to conform to complex shapes.

The panel noted that the Japanese have excelled in developing focused, special-purpose systems, some of which could find applications in space: a ladder-climbing robot; a teleoperated live-line maintenance robot; an inspection robot for containment vessels; vacuum-compatible actuators and robots; bipedal walkers; a plant tissue culture robot that can select, grasp, cut, and transport seedlings; and a piano-playing robot that can read and play music.

Perspectives

Vision and planning, coupled with a strong robotics research infrastructure, are enabling the young Japanese space program to develop relevant systems for space. Many successful Japanese development programs involve a stair-step approach, or rapid prototyping of technology generations, rather than a continuous evolution or one-time technological leap. The typical Japanese approach to robotics system challenges has been, and will probably continue to be, to first develop and deploy a baseline capability. System improvements can then take the form of distinct incremental upgrades.

At the same time, the Japanese often display a minimalist approach to space robotics technology. In some of their robots, they use technology adequate to getting the job done, thus avoiding the major costs associated with concerns about future evolution. To a marked degree, the Japanese tend to incorporate special-purpose electronics and devices (digital signal processors, application-specific integrated circuits, very large-scale integration, and special-purpose actuators) into their robotics. Overall, Japanese robotics hardware is more notable than its associated software.

The panel concluded that the Japanese were significant participants in space robotics with everything necessary to succeed: the technology, experience, and commitment to reach their objective of competent space robots.

SPACE AND TRANSATMOSPHERIC PROPULSION TECHNOLOGY

September 1990

Charles Merkle, Penn State University (Panel Chair)

Maynard L. (Joe) Stangeland, Rockwell International

James R. Brown, Pratt & Whitney

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G. Burton Northam, NASA Langley Research Center

Edward E. Zukoski, California Institute of Technology

SUMMARY

This report focuses primarily on Japan's programs in liquid rocket propulsion and propulsion for spaceplane and related transatmospheric areas. It refers briefly to Japan's solid rocket programs and to new supersonic air-breathing propulsion efforts.

Japan's long-term plans for space activity and its generic paths for achieving these plans were originally outlined in 1978 in the *Fundamental Policy of Japan's Space Development*. This document was revised in 1984 and 1989, and was expected to be updated periodically to keep Japan's policy consistent with advances in technology and changing socioeconomic factors. It shows Japan's space program to be a very aggressive and forward-looking one. This program emphasizes development of internal resources for various domestic and international space activities. Japan's domestic space interests encompass activities to exploit the unique environmental conditions of space, prepare for civil space development, and promote manned space activities. Plans for international collaborations include cooperating with programs established by other countries, initiating collaborative programs, and assisting developing countries.

Japan's space program is founded on two basic tenets: development of assured access to space and use of space activities solely for peaceful purposes. Work conducted by NASA with the U.S. Air Force might conflict with Japan's guideline concerning peaceful uses of space. However, there should be ample room for cooperative Japan-U.S. space endeavors. Japan's goals for the 1990s include plans

for continuing its already strong thrust in scientific space research, bringing its satellite and launch technologies up to international standards, creating the infrastructure for space station activities, and developing the basic technologies required for manned space activities.

Space transportation systems are of primary importance in Japan's near-term space plans. Near-term goals in space transportation are aimed at the development of an expendable launch system for transporting materials to geostationary orbit, technology for unmanned space-to-ground transportation, and fundamental R&D for long-term manned space transportation capabilities. Current transportation plans for expendable launch vehicles focus on developing and enhancing the H- and M-series of liquid and solid rocket systems.

General Findings

Japan has several distinct space transportation efforts, including three expendable rocket launch vehicle programs and three air-breathing hypersonic vehicle concepts. The rocket launch vehicles include operational and developmental systems -- the N-series, the H-series, and the M-series. Air-breathing hypersonic vehicles were in the concept definition phase at the time of the panel's visit. The N-series of launch vehicles is based on U.S. technology developed under license. H-I vehicles include technology based in part on Japanese design and development and in part on licensed U.S. technology. The H-II vehicle, scheduled for first use in 1993, is completely Japanese in design, and positions Japan as a full-fledged member of the world launch community. The M-series rockets, solid boosters of Japanese design, are highly advanced and have proven capabilities for launching scientific satellites.

Japan's Tanegashima launch facilities are at nearly the same latitude as the U.S. facilities at Kennedy Space Center. The size of the launch site at Tanegashima is much smaller than that at Kennedy, and transportation facilities in the immediate area are somewhat limited. But these facilities appear to be adequate for the H-II. An agreement with local residents limits launch windows to a few weeks per year.

At the time of the panel's visit, engine development for Japan's space transportation efforts was divided into eight programs in stages ranging from concept development to operational: four cryogenic hydrogen-oxygen rocket engines and four advanced air-breathing systems. In conjunction with the H-series expendable launch vehicle program, the LE-5 cryogenic propulsion engine was operational, and propulsion development was under way for the LE-5a and the LE-7 cryogenic engines. Also under development were the HIPEX expander cycle engine, an additional new liquid hydrogen-oxygen engine; the liquid air cycle engine (LACE), a generic propulsion system oriented towards advanced air-breathing systems such as strap-on boosters for upgraded versions of the H-II; and the ATREX engine, an air turboramjet system. The remaining two propulsion systems were a scramjet engine concept intended for eventual hypersonic applications and a newly announced Mach 5 turbojet/ turboramjet engine being developed for high-speed commercial transportation.

The panel found the systems and performance of Japan's cryogenic liquid rocket engines to be comparable to those of engines developed in the United States. The Japanese made extensive use of U.S. data, procedures, and technology in their designs; their engines also have similar specific impulse and vacuum thrust-to-weight ratios. However, the new engines are decidedly Japanese designs, showing a number of subtle but significant philosophical differences from U.S. systems. Japanese engine development programs were composed of carefully planned steps involving low-risk, well-characterized options. Japan's slightly more conservative design approach may facilitate reliability and be particularly beneficial if the engines or their derivatives are man-rated.

In the area of turbomachinery, Japanese turbopumps and turbines demonstrate performance levels similar to those of U.S. products. The Japanese are behind the United States in some areas of turbomachinery but ahead in others. In one instance they chose a two-stage over a three-stage pump to avoid a technology development program. Their cooperative efforts minimize duplication and maximize the rate of advancement.

By 1989, the Japanese were beginning a study of spaceplane concepts that emphasized such diverse topics as aerodynamics, structures, slush hydrogen fuel, Computational Fluid Dynamics (CFD), advanced propulsion, and system development scenarios. The propulsive cycles under study included the turbojet, the ramjet, the turboramjet, and the supersonic combustion ramjet (scramjet). The propulsion systems of primary interest appeared to be those for the Mach 3 to Mach 6 range for the low-Mach-number portion of hypersonic cruise or SSTO vehicles, strap-on booster augmentation engines for launch systems, or air-breathing engines for a civilian SST. Efforts in higher Mach number propulsion systems were directed more toward accumulating a database.

In engine development, the panel found two classes of engine in the prototype phase: the LACE engine at Mitsubishi Heavy Industries and the ATREX air turboramjet at Ishikawajima-Harima Heavy Industries. The LACE demonstrator engine used the LH2 pump and combustor from the LE-5 engine, along with new components for the air liquefier and the liquid air pump. The ATREX engine relied on existing turbojet-turbofan production and design experience and on the expander cycle technology developed in the HIPEX engine.

The Japanese program in scramjet applications was only in the concept definition phase when the JTEC panel visited. Scramjet technology programs included experimental studies of supersonic combustion, including ignition and diffusion flame studies, and shock tube studies of elementary reaction kinetics of hydrogen. High-

C-2.

speed inlet tests on a scale model were under way, as were university efforts in hypersonic reacting flows and component technology for advanced propulsion systems.

In advanced fuels development and on-plant construction for hydrogen production, Japan had two high-density hydrocarbon fuels for rocket applications, and was stepping up its hydrogen production capabilities to serve the H-II and advanced air-breathing propulsion systems. It was building a plant that made hydrogen as the by-product of ethylene production and a pilot facility to produce hydrogen from coal.

Japan was using the latest U.S. and European advanced diagnostics systems, but was leading in the development and manufacture of many of the basic lasers, optics, and electro-optic components for these systems. Tunable diode lasers and a surface-emitting diode laser with reduced beam divergence were developments in advanced diagnostics implementations that offered possibilities for improved spatial resolution.

CFD, important in all propulsion development, was seen to be an area of strength in Japan. Japanese supercomputers were acknowledged to be among the best in the world, and their availability had resulted in rapid progress in computational areas. The Japanese routinely included real gas effects and complex reaction kinetics in flow field analyses, and their codes were based on the latest algorithms. Their visualization and postprocessing capabilities were also at the leading edge. The Japanese had appropriate CFD capabilities to move rapidly in this aspect of propulsion development.

Conclusions

The panel observed that the Japanese had a carefully thought-out plan, a broad-based program, and an ambitious but achievable schedule for propulsion activity. Japan's overall propulsion program was behind that of the United States at the time of this study, but the Japanese were gaining rapidly. The Japanese are at the forefront in such key areas as advanced materials, enjoying a high level of project continuity and funding. Japan's space program has been evolutionary in nature, while the U.S. program has emphasized revolutionary advances. Projects have typically been smaller in Japan than in the United States, focusing on incremental advances in technology, with an excellent record of applying proven technology to new projects. This evolutionary approach, coupled with an ability to take technology off the shelf from other countries, has resulted in relatively low development costs, rapid progress, and enhanced reliability. Clearly Japan is positioned to be a world leader in space and transatmospheric propulsion technology by the year 2000.

VI. ENERGY

EUROPEAN NUCLEAR INSTRUMENTATION AND CONTROLS

December 1991

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David D. Lanning, MIT (Panel Cochair)

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Lester C. Oakes, EPRI

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BACKGROUND

A panel of U.S. specialists conducted a study of instrumentation and controls (I&C) technology used in nuclear power plants in Europe. These findings relate to the countries visited and to pressurized water reactor (PWR) nuclear power plants. The panel visited France, Germany, the Soviet Union, Czechoslovakia, and Norway.

SUMMARY

The U.S. is behind in the application of advanced instrumentation and controls in nuclear reactors. All European countries that operate nuclear power plants, as well as Canada, Japan, and the U.S., are moving toward use of digital computers, especially microprocessors, in information and control systems. The operator's role varies by country. Japan and Germany are moving toward a high degree of automation, whereas in France the emphasis is on computer-generated procedures with the decision to enable being made by skilled operators. In U.S. and Soviet plants, the emphasis is on using digital systems to help the operator identify problems, decide on the appropriate corrective actions, and aid in the execution of those actions.

The U.S. is behind in the development and experience of using digital systems in nuclear plants, and in the use of fault diagnosis and signal validation systems. The hardware for digital systems used in all countries comes mostly from U.S. computer companies, but the lack of deployment of digital systems in U.S. nuclear plants has kept the U.S. behind in developing experience in computer system architecture for nuclear I&C systems. The Europeans are also ahead in the use of computer assisted software engineering (CASE) tools and in the development of standards. European instrumentation for nuclear power plants is similar to that in the U.S., although some special instrumentation is being developed.

An advantage to being behind is that the U.S. can learn from the mistakes of those ahead. The digital systems' programmability can entice the user to add complexities that can evolve into problems. Efforts must be made to maintain simplicity.

Qualitative Comparisons

The panel made a qualitative comparison of the U.S. and Europe in instrumentation and controls for nuclear power plants. Figure 22 shows the standing of the countries visited relative to the U.S.

	BASIC RESEARCH	ADVANCED DEVELOPMENT	PRODUCT IMPLEMENTATION
Control Room Des.	+ →	+ ↗	+ ↗
Analog-Digital Trans.	0 →	+ ↗	+ ↗
Support Systems	+ ↗	+ ↗	+ ↗
Control Strategies	+ →	+ ↗	+ ↗
Architecture	— ↘	— ↘	+ ↗
Instrumentation	0 →	0 →	0 →
Standards & Tools	+ →	+ →	+ ↗

Jan. 1991

+ indicates Europe ahead

↗ Indicates Europe gaining ground

Figure 22. Summary Comparison of Nuclear Power Plant I&C in Europe and U.S.

As shown in Figure 22, Europe is ahead of the U.S. and moving ahead further in implementation of products in all seven categories, with the possible exception of instrumentation. In the area of advanced development, Europe is also ahead except for architecture and instrumentation. In basic research, Europe is ahead in four of the seven categories; however, for analog-to-digital transition and for instrumentation, the U.S. is about equal, and the U.S. is ahead in architecture. In other words, U.S. computers are being purchased and utilized in all countries that the panel visited, but the development and implementation of the computers for nuclear power plant instrumentation and control is more advanced in Europe.

Evolution of Automation in Nuclear Power Plants

There is a move in every country designing nuclear power plants to improve the plant's availability, safety, ease of operation and/or acceptability by the public and regulators. The appropriate balance of automation and manual operation is the subject of considerable debate in the U.S. and Europe today. Most researchers agree that today's technology would support digital automation of all the major systems in a power plant. One of the concerns, however, is how to verify and validate the required software.

In the U.S., the transition from today's nuclear control systems to more automated future designs is likely to occur in phases. One of the purposes of this study was to determine where the European concepts were in terms of evolution of I&C. The U.S. transition may be described in terms of four levels (see Fig. 23). The solid diamonds represent a plant that is operational; empty diamonds represent plants that are not yet operational.

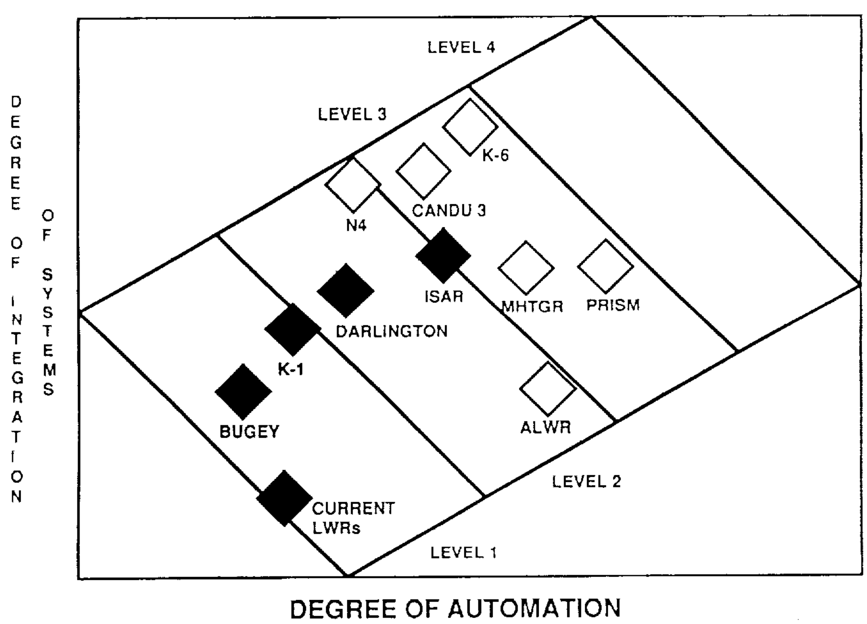

Figure 23. Nuclear Plant I&C State of the Art

In level 1, some of today's analog controllers will be replaced with more reliable digital controllers performing basic proportional-integral-differential (PID) control. This phase of evolution is already under way in the U.S. Generally, digital implementations of control systems on U.S. reactors have been one-for-one replacements of the original analog systems and have not taken full advantage of recent technological developments. As the chart shows, the panel thinks U.S. LWRs are in the beginning of level 1. The French plant Bugey is a little further advanced but also in level 1, while the Japanese Tokyo Electric Power Company's Kashiwazaki-1 and -2 are at the interface with the next level.

Level 2 of the predicted transition will include automation of routine procedures like plant start-up, shut-down, refueling, load changes, and certain emergency response procedures. Significant assistance will be given to the operator through computer-based expert systems and control room displays of plant status. Control will be implemented with digital technology. The newly completed Darlington plant in Canada is at level 2, as are the U.S. Advanced Light Water Reactor (ALWR) and the newest French plant (the N4 class). The German ISAR-II is between levels 2 and 3.

Level 3 is a significant advance toward automation with the operator interacting with and monitoring an intelligent, adaptive supervisory control system. Smart sensors will be expected to validate signals and communicate with fault-tolerant process controllers. Control strategies will be adaptive, and very robust to off-normal conditions. Advanced LMR (PRISM) concepts and MHTGR concepts being studied by the U.S. DOE will have these capabilities. The newest Canadian concept, the CANDU 3, is placed in this category, as is the Japanese Advanced Boiling Water Reactor (ABWR).

Level 4 would be characterized as total automation of the plant, with an intelligent control system aware of operational status and in interactive communication with the operator to keep him apprised of any degraded conditions, likely consequences of these conditions, and possible strategies for minimizing deleterious consequences. At this point most plant functions will be automated and robotized including maintenance and security surveillance.

The control and information system will be an integral part of not only the total plant design, but also the national network of commercial power plants. The control system computer will learn from the network relevant information concerning other plants and component operational experience, and will alert the operator if that experience is relevant to his plant. No U.S. design has gone this far in incorporating advanced technology and automation. The Japanese Frontier Research Group on Artificial Intelligence is working on conceptual definition of a plant of this type. In the evolution of higher levels of automation, the designers will try to improve all aspects of nuclear power plants, including safety and reliability. Progress in all countries should build on successes and experiences in other countries.

NUCLEAR POWER IN JAPAN

October 1990

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SUMMARY

The JTEC panel on nuclear power in Japan examined the status and direction of nuclear power-related research and development in Japan in six areas: the nuclear fuel cycle, nuclear materials, instrumentation and control technology, CAD/CAM, nuclear safety research, and nuclear plant construction. The panel based its report on a review of literature and a one-week trip to Japan in January 1990 during which panel members visited numerous Japanese laboratories and other nuclear facilities. The panel found that the nuclear power industry in Japan was at an advanced state of development; Japan had become technologically self-sufficient. Long-term goals of the Japanese program included closure of the complete fuel cycle and pursuit of the liquid metal fast breeder reactor as the future base system.

The Context of Nuclear Power in Japan

The panel found the Japanese program of nuclear power research and development to be blessed with many benefits, including a strong, consistent federal commitment to nuclear power; an adequate supply of R&D funds; a stable set of priorities for R&D; a well-developed distribution of responsibilities between the public and private sectors; and a highly capable group of agencies engaged in R&D. In 1955, Japanese policymakers, recognizing that their nation lacked indigenous energy sources, made a commitment to develop nuclear power as the most likely vehicle for achieving a self-reliant electric energy supply system. This key decision has remained a cornerstone of Japanese energy policy.

The structure in which the nuclear program evolved included a well-developed long-range plan, a clear distribution of obligations among plan participants, a strong utility industry capable of constructing and operating plants and learning from its experiences, a strong supply sector capable of designing plants and developing the designs toward the ultimate goal, and a commitment to adequate funding for nuclear R&D to ensure the quality and completeness of the effort. Other factors became important, but none were displaced or downgraded. Public opinion grew negative toward nuclear power, particularly after Chernobyl. Safety grew increasingly important in Japan. The industry devoted considerable resources to ensuring safe operations and conducting safety research. But this added emphasis came as an addition to ongoing efforts, not as a replacement.

The Research and Development Focus

The Japanese nuclear research program is dominated by light-water reactor (LWR) technology, the nuclear fuel cycle, and advanced reactors. These three areas consumed about $1.5 billion in 1989 R&D funds. LWR technology is supported mainly by the electric utilities and the vendors. Research focuses on improvements in plant safety and in economics. They are working to develop improved, extended burnup fuels for nuclear power plants. Another important area is controls and instrumentation, including advanced control room design. Longer-range research focuses on developing advanced LWRs of both the boiling water reactor (BWR) and pressurized water reactor types.

Closure of the nuclear fuel cycle is a priority for the Japanese. They do not wish to rely on external suppliers for enrichment services or reprocessing services. This R&D is being done primarily at government research laboratories. Government expenditures on the fuel cycle were $280 million in 1989, and the utility contribution was $200 million. The largest expenditure, about $180 million, was for reprocessing. The Japanese, foreseeing a need for plutonium in their future breeder economy, are committed to having all of the reprocessing technology developed and in place in advance of the widespread deployment of fast breeder reactors (FBRs). The long-term goal of the fuel cycle research is complete self-sufficiency, with the ability to handle enrichment, fuel fabrication, reprocessing, and waste storage; the near-term goal is to require only uranium ore and to be self-sufficient in all other aspects of the cycle.

The largest nuclear R&D expenditures are for the advanced reactor program, which accounted for $775 million in 1989. The FBR received $650 million, or nearly 85 percent of the total advanced reactor budget. The key project is the Monju reactor. Similar in design to the Clinch River Breeder, the Monju reactor is a 280 MWe liquid metal fast breeder reactor. At the time of the panel visit, construction was about 80 percent complete, with initial criticality scheduled for 1992.

Specific R&D Comparisons

Nuclear Fuel Cycle. Japan is committed to the complete fuel cycle -- uranium mining, conversion, enrichment, irradiation, reprocessing, and waste disposal. Unlike the U.S., Japan includes plutonium utilization and uranium recycling in its nuclear program as a matter of national policy. As part of the effort to develop a complete fuel cycle, the Japanese participate aggressively in international cooperative efforts. Such efforts encompass university and national laboratory programs and cooperation with government and industry organizations worldwide to achieve the best engineering and most effective commercialization for all parts of the fuel cycle.

Nuclear Materials. Japanese materials research began from a base that incorporated much initial U.S. research. Japan's LWR plants have higher energy availability than U.S. plants for several reasons, including improved materials. Because of their careful control of water chemistry and materials selection, the Japanese have had very few problems with Intergranular Stress Corrosion Cracking in their BWRs or steam generator problems in their PWRs. The Japanese are conducting research on extended-life fuels for both the BWRs and PWRs with the objective of extending the operating cycle to eighteen months without suffering fuel failures. Meeting this goal would increase plant availabilities to over 80 percent. The Japanese also have demonstrated interest in load following, and considerable effort is underway to develop and test long-lived fuel that could be cycled in power. Advanced reactor materials research is primarily directed toward breeder fuels and work related to U-Pu fuels for use in LWRs. A small amount of research is being done on high-temperature, gas-cooled reactor fuels.

Instrumentation and Controls. Application of improved instrumentation and controls (I&C) to nuclear power plants appears to be much farther along in Japan than in the U.S. The panel attributed this progress to Japan's long, productive R&D commitment and its healthy industry. The Japanese have demonstrated particular interest in several specific technologies. National labs, vendors, and universities have vigorously pursued work in artificial intelligence and expert systems, with applications in component diagnostics and operator support systems. Fiber optics are being used in some existing plants and will be used in new plants. The subject of man-machine interfaces was receiving a great deal of attention in Japan. Research was focusing on clarification of human behavioral characteristics, systematic applications of behavioral information, and organizational and systems aspects of human error experience.

The panel found no evidence that Japan was ahead of the U.S. in basic research. Indeed, the U.S. retains a lead in several areas, including information theory and advanced computer languages.

CAD/CAM Technology. CAD/CAM technology has reached comparable levels of development in Japan and the United States. Both nations are using CAD/CAM to develop three-dimensional models of conceptual designs of new plants. Common databases are being used by different designers for technical areas such as reactor physics, thermal hydraulics, and piping. The Japanese nuclear power program provides the opportunity to incorporate application into the design and fabrication activities because real plants are being developed and built.

The Japanese are actively pursuing further development of CAD/CAM systems. Near-term goals include full 3-D design capability, common databases, and interactive communication with designers. Longer-term goals include detailed design, procurement documents, and manufacturing specifications. Databases would be generated for the as-built system for use during plant operation. The panel felt that the United States remained the leader in conceptualizing and developing software, CAD/CAM systems, database management programs, system integration, and nonnuclear-related applications. The tendency in Japan was to purchase completed packages and adapt them for use in specific applications.

Nuclear Safety. Concern about nuclear plant safety has permeated the design and operation of nuclear plants in both the U.S. and Japan. However, there are significant differences between the two nations in safety R&D. In Japan, safety is seen as a matter of such great importance that even minor events must be avoided. As a consequence, much safety R&D in Japan focuses on operational issues. In the U.S., the key element of safety research is severe accident scenarios.

Japan's government R&D is closely tied to support of regulatory activities. Large-scale test facilities are maintained for research in thermal hydraulics, two-phase flow, and seismic testing of components and systems. Results from the research are used to validate computer models of systems behavior. In general, the panel found the U.S. ahead of Japan in conceiving and developing such codes. However, the Japanese enhance the codes more completely, using experimental data for validation. The Japanese emphasize human factors in nuclear safety R&D. Vendors use research results to improve control room design and support systems evaluation. The Japanese have been slow to enter the field of probabilistic safety assessment because of the view that, since severe accidents will not occur at their plants, they have no need for Level 3 capability. Nevertheless, the issue was under active study at the time of the panel's visit. In Japan much applied AI work is conducted by federal labs, utilities, and vendors, though there is little coupling to academia.

Nuclear Power Plant Construction. Japan has been more successful than the U.S. in holding down the cost of constructing nuclear power plants. Institutional, regulatory, and cultural differences account for the higher cost of U.S. construction. Japan has also achieved effective nuclear regulation with far less disruption and delay in construction and licensing than has occurred in the United States. Japan's improvements in the construction process include (a) shop fabrication of very large modules that are shipped to the site and installed; (b) substantial completion of detailed engineering drawings before start of construction; (c) fully computerized, comprehensive construction sequence plans; and (d) comprehensive quality assurance programs with detailed inspection, but performed to minimize interference with construction. Japan was at an early stage in applying robotics to field construction at the time of the panel's visit.

Japan spends more on construction-related R&D than the U.S., and is more effective at transferring new technology into construction. Japan's nuclear industry is applying the latest design improvements and new technology from R&D to construction. The only opportunities for U.S. manufacturers and A/E firms to apply developments have been in overseas projects, such as those in Korea. Without new construction activity, the U.S. could lose parity with Japan in construction-related R&D and associated infrastructure. These trends could lead to higher electricity prices for U.S. consumers and an increased competitive disadvantage for U.S. manufacturers in global markets.

VII. Biotechnology

BIOPROCESS ENGINEERING IN JAPAN

May 1992

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BACKGROUND

The goals of the JTEC report on bioprocess engineering were to assess the status of bioprocess engineering and biotechnology, as well as to compare trends in the U.S. and Japan in areas relating to the biotechnological processes. The panel also sought to assess major differences between the U.S. and Japan in bioprocess engineering research and development.

SUMMARY

In Japan, biotechnology activities occur primarily in large companies; few if any small biotech start-ups are apparent. Many Japanese companies with major efforts in biotechnology began in other fields of manufacturing. The product portfolio of the present Japanese biotechnology market is similar to that in the United States. Total sales increased 48 percent in 1990, to a total of $2.187 billion.

Molecular Biology

Japanese research in molecular biology and biological sciences is similar to that in the U.S. Japanese research is directed towards both prokaryotic and eukaryotic organisms. However, the panel did not notice any novel prokaryotic expression system under development in Japanese laboratories. Systems used for protein expression in prokaryotic organisms are similar to those employed in the United States. There is a very noticeable emphasis in Japan on research using eukaryotes, particularly in animal and mammalian cell systems. Lastly, the dominant opinion in Japan is that, for human therapy, murine antibodies will not be the major targets. Instead, humanized antibodies will be their choice.

Upstream Bioprocessing

Bioprocess engineering R&D philosophy in Japanese laboratories dealing with upstream technologies, such as recombinant protein production in bacteria and animal cells, differs from that in the U.S. The Japanese do not appear to emphasize the use of basic engineering principles for process development or process scale-up. Instead, the emphasis is much more biological, including screening, selection, and medium development. Also, automation in upstream technology is being developed extensively to reduce the human interface. One observation concerning Japan's upstream manufacturing technologies is the similarity to what they have acquired or licensed from the U.S. In the long run, Japan could move ahead of the U.S.

Downstream Bioprocessing

In downstream processing, the panel saw no new advances in product isolation and purification. Chromatographic media and methodology development is being carried out by Japanese companies that supply chemicals, biologicals, equipment and process expertise to the biomanufacturing sectors. There is noticeably intense activity in the area of in-vitro protein refolding. Many industrial laboratories have a heavy focus on protein refolding, but the panel learned little about their progress.

University Training and Education

Research training and education for biotechnology and bioprocess engineering in Japanese universities is different from that in the U.S. Most Japanese research and educational programs are not driven by engineering principles and are located in other disciplines. Japanese university programs focus on applied research, which contrasts with the basic orientation of U.S. efforts. Lastly, the involvement of industrial and foreign investigators in Japanese university laboratories is extensive.

Bioprocess Engineering

Bioprocess engineering R&D by Japanese companies is not driven by generic engineering principles, a situation similar to that found at Japan's universities. Process development activities are often performed directly at the manufacturing site rather than within the company's R&D laboratories.

Many Japanese government agencies support and perform basic and applied research in bioprocess engineering and biotechnology. The agencies help identify directions for Japan's biotechnology R&D. Government support for R&D is often long-range, with a typical planning horizon of ten years. The government has fostered development of an international network in advancing Japan's biotechnology program.

Future Trends

Japanese industry is focused on molecular biology efforts to use prokaryotic organisms for producing therapeutic proteins. Japanese industry has targeted recombinant products that the U.S. has already developed. It is evident that Japan plans to be a world player in the use of prokaryotes to compete in the pharmaceutical market.

The Japanese biotechnology industry has targeted animal cell cultures as vehicles for the production of therapeutic proteins. Due to their acquisition of U.S. cell culture processes, the Japanese are also in an excellent position to improve existing manufacturing methods. Japan's bioprocess engineering efforts will be competitive with and could even surpass those of the U.S. in the years to come.

There is a large research effort in Japan on protein engineering. However, the basic principles, software, and hardware presently employed are mostly from abroad. Japan has traditionally dominated many areas of bioprocess engineering and biotechnology; there is no sign that they have decreased their efforts in these areas. However, there is no counterpart when compared with the U.S. in the development of those potentials in biotechnology manufacturing systems. The Japanese biotechnology sector is rapidly entering into bioprocess manufacturing by using know-how either acquired or licensed from the U.S. This will reduce process development time and costs significantly, and speed Japan's market entry.

Qualitative Comparison Between the U.S. and Japan

The JTEC panel prepared a qualitative comparison summarizing the present status and future trends in the U.S. and Japan in various areas relating to biotechnological processes (see Fig. 24).

		Now	Future
MOLECULAR BIOLOGY	PRODUCT DISCOVERY	-	↘
	GENETICS	-	↘
MICROBIOLOGY	SCREENING	+	↗
	STRAIN DEVELOPMENT	+	↗
	FERMENTATION TECHNOLOGY	+	↗
UPSTREAM BIOPROCESSING	PROCESS DEVELOPMENT	O	→
	ENGINEERING SCIENCE	-	↘
	MONITOR AND CONTROL	+	↗
	BIOREACTOR SCALE-UP	-	↘
DOWNSTREAM BIOPROCESSING	SOLID-LIQUID SEPARATION	O	→
	CELL DISRUPTION	O	→
	MEMBRANE TECHNOLOGY	-	→
	AFFINITY CHROMATOGRAPHY	-	↘
	ION-EXCHANGE CHROMATOGRAPHY	-	→
	SIZE EXCLUSION CHROMATOGRAPHY	O	→
	HPLC	O	→
	PROTEIN REFOLDING	-	→
BIOCATALYSIS	ENZYME DISCOVERY	+	↗
	ENZYME SCIENCE	—	↗
	ENZYME ENGINEERING	+	↗
	INDUSTRIAL IMPLEMENTATION	+	↗
OTHER MANUFACTURING ISSUES	CONTAINMENT	—	↘
	cGMP	—	↘
	TECHNOLOGY MANAGEMENT	+	↗
EDUCATIONAL STATUS	BASIC TRAINING	—	↘
	APPLIED TRAINING	+	↗
	ENGINEERING VS. SCIENCE	—	↘
	FACULTY BIOTECH KNOWLEDGE	—	→
UNIVERSITY GOVERNMENT, INDUSTRY INTERACTIONS	UNIVERSITY-INDUSTRY	+	↗
	UNIVERSITY-GOVERNMENT	+	↗
	GOVERNMENT INDUSTRY	+	↗
	OVERALL	+	↗

\+ = Japan ahead 0 = even - = Japan behind

↗ = Japan gaining ↘ = U.S. gaining

Figure 24. Qualitative Comparison Between the U.S. and Japan in Biotechnology Processes

BIOTECHNOLOGY IN JAPAN

June 1985

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SUMMARY

This panel used information gathered primarily from Japan to assess Japanese research and development in several of the main areas of biotechnology. The five areas of biotechnology evaluated were biochemical process technology, biosensors, cell culture technology, protein engineering, and recombinant DNA technology. The panel found that biochemical processing was an important growth industry in Japan, but there was room for the United States' biochemical processing industry to develop competitively. In biosensors, the Japanese developments were considered to have a high chance of commercial success. In cell culture technology, panel members found it difficult to assess Japan's competitiveness in this very new area; however, judging by the current interest and research activity in large-scale cell culture, they felt that Japan was likely to become a significant competitor in the future. At the time of the study, there was little protein engineering activity in Japan. However, the panel found the Japanese to be very much interested in the application of protein engineering to develop industrial enzymes, pharmaceuticals, diagnostics, sensors, and microelectronics. Japan appeared to be taking a relatively long view with respect to commercializing this technology. In the area of molecular biology and genetics, funding for basic research had lagged in Japan, but the panel felt that the national focus on recombinant DNA technology should improve Japan's competitive position.

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